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PROGRAM ON APPLICATION OF COMMUNICATIONS SATELLITES TO EDUCATIONAL DEVELOPMENT

WASHINGTON UNIVERSITY

Internal Memorandum No. 71-1 April 10, 1971

COMPUTER-BASED INSTRUCTION:

A Background Paper on its Status, Cost/Effectiveness and Telecommunications Requirements

Jai P. Singh
Robert P. Morgan

This research is supported by the National Aeronautics and Space Administration under Grant No. Y/NGL-26-008-054. This memorandum is strictly for internal distribution and does not necessarily represent the views of either the research team as a whole or the National Aeronautics and Space Administration.

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SUMMARY

Washington University has undertaken a NASA sponsored program on Application of Communication Satellites to Educational Development. This memorandum has been prepared to provide essential background information on Computer-Based Instruction (CBI); its status, cost-effectiveness and telecommunications requirements. In this latter regard, particular attention is given to the role of telecommunications, and particularly communication satellites, in large-scale totally and partially centralized CBI systems and in extending CBI services to rural, small and less-affluent communities and schools.

In slightly over twelve years since its inception, CBI has shown promise of being more cost-effective than traditional instruction for certain educational applications. Pilot experiments are underway to evaluate various CBI systems. Should these tests prove successful, a major problem confronting advocates of large-scale CBI utilization is the conflict between the organization of the traditional school system and optimal methods of utilizing computer-based instruction. This memorandum discusses the larger issues involved and presents a summary of experiments and costs of a variety of CBI experiments and approaches.

Large-scale and intensive utilization is the key to low per-pupil costs. Some means of low-cost telecommunications must be found if rural communities and sparsely populated regions are to benefit. Communication satellites seem to hold distinct advantages over existing commercial telephone communications for linking remote terminal clusters with a central computer where computer-cluster separation is 150-200 miles or greater.

COMPUTER-BASED INSTRUCTION:
A BACKGROUND PAPER ON ITS STATUS, COST/EFFECTIVENESS AND TELECOMMUNICATIONS REQUIREMENTS*

1. INTRODUCTION

The role of computers as an active element in the instructional process has been under investigation for more than 12 years, and the field continues to advance rapidly from year to year. The beginnings of machine teaching could be traced to the pioneering work of S. L. Pressey[1] in 1926 and to B. F. Skinner's refinement of programmed learning[2] during the latter 1950's. A few people with computer background as well as broad enough outlook to comprehend the potentials of programmed instruction began to visualize the opportunities that could be realized if the computer could be used to manage the administration of highly sophisticated programmed material. In 1958, first projects in computer teaching were begun at the IBM Watson Research Center, Systems Development Corporation, and Bolt, Bernek, and Newman. According to a recently published survey[3], at present more than 100 projects of all sizes and levels are being conducted on research, development and actual use of interactive computer systems as compared to some twenty in 1965 and five in 1961. At least three factors may be cited as having contributed or contributing heavily to the growth of computer-based instruction (CBI).

(a) The rich and intriguing potential for meeting an educational need through its learner-centered nature - the need being the individualization of instruction.

(b) The mushrooming of electronic data-processing in general and more specifically, the introduction of time-sharing systems in early 60's.

(c) The increasing aid to education by the Federal Government. In particular, the National Science Foundation, Bureau of Research of the Office of Education, and various other funding agencies which came into being under the Elementary and Secondary Education Act of 1965 have contributed significantly to the growth of CBI. As of October 23, 1968, the Bureau of Research (OE) had invested $ 35.57 million in computer related projects with a substantial portion of it going to CBI/CAI/CMI projects[4]. Research agencies connected with the Department of Defence, such as Advanced Research Projects Agency (ARPA), Joint Services Electronics Program, Office of Naval Research, etc. have also invested substantial sums of money into CBI/CMI projects.

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*This is one of a series of memoranda on educational telecommunications needs. The authors wish to thank Mrs. Emily Pearce for the very skillful typing of the manuscript.

2. CBI vs CAI vs CMI etc.

Before proceeding further with discussions related to active teaching by computer, some clarification about the terminology is in order. Active teaching by computer is known by many names: Computer-Assisted Instruction (CAI), Computer-Managed Instruction (CMI), Computer-Based Instruction (CBI), Computer-Assisted Learning (CAL), or Computer-Assisted Teaching (CAT). Although, CAI is the most popular and common name used, a single underlying idea persists among all these names, that is, the computer is used to aid and abet both teacher and students in the educational process[3]. CAI, in particular, is a man-machine relationship in which a man is a learner and the machine is a computer-system. Two-way communication exists between them, with the objective being human learning and retention. During instruction, the only humans in the system are the learners[5].

The mere presence of a computer in an instructional environment is not sufficient to meet an acceptable definition of a CAI system. To be CAI, the computer must actually instruct the student, and not be simply a tool to assist in problem solving or retrieving information: that would be CAS, Computer-Assisted Student. When a teacher uses a computer to aid in demonstrating problem solutions, this would be CAT. In the instances cited above, all of which involve a computer, learning may occur, but the term CAI* should be reserved for those particular learning situations in which a computer contains a stored instructional program designed to inform, guide, control and test the student until a prescribed level of efficiency is reached[5].

Here it should be noted carefully that CAI is not synonymous with Programmed Instruction (PI) as some may think. It is true that much of the early CAI software was merely a translation of PI texts. Today the computer is usually programmed to calculate unique responses to varying student inquiries by making use of the algorithms stored in its memory[6]. As opposed to PI, it is not necessary for the programmer to anticipate all conceivable student responses so as to compare them with "correct" answers stored in the machine. PI is unable to cope with teaching strategies which do not call for specified student responses but in CAI these strategies are usable. In the PLATO system (University of Illinois, Urbana), teaching strategies which do not require specified student responses are widely used and they have been cited of being greater value than strategies requiring specific responses in many fields and levels of information[6].

Another application that is developing very rapidly is the use of a computer to monitor the instructional process, whether it is computer-based or the traditional teacher-administered instruction. The phrase "Computer-Managed Instruction" (CMI) has been used to describe such systems[7].

The purpose of a CMI system is to provide diagnostic and prescriptive information to the instructor (man/machine) to assist him/it in making instructional decisions. For example, performance data can be used for deciding how to alter the pacing of lessons, to choose supplemental instruction materials, to regroup students (in case of teacher administered instruction), to make referrals, to prescribe individual instruction activities, to revise instructional objectives, to modify the sequence of instruction, or to revise instruction in any way that may facilitate student achievement of instructional objectives. There

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*The terms Computer-Based Instruction (CBI) and Computer-Assisted Instruction (CAI) have been used interchangeably throughout this memorandum. The term CBI connotes a wider and more central role of computers in instruction than that conveyed by the term CAI.

is no reason why a computer system used for CAI cannot also offer the instructional management facilities described above. A CMI system computer may not be on-line and not have time-sharing capability because the student is not needed to be on-line with the computer. Thus the CMI system cannot always be also used for CAI as opposed to the possibility of a CAI system being used for CMI purposes. In fact, CAI software may include CMI objectives.

Silberman[7] points out that CMI, unlike CAI, does not require a large number of expensive terminals and could be easily implemented, with considerably less cost than CAI, by taking advantage of conventional Electronic Data Processing (EDP) equipment. CMI also has an important advantage as it is not a substitute for a teacher, merely an aid, and hence less resistance is expected to its introduction. CMI could be an interim step towards CAI.

It is not very likely that all schools will be owning their own EDP equipment in the near-future. In rural areas, even school districts may not have their own computer systems. Thus, it is felt that either remote-batch processing or time-sharing could be used for CMI along with other administrative data processing.

Before looking into the possible telecommunications requirements for CAI in detail, it would be appropriate to take a quick look to the current status of CAI in terms of utilization, cost and technology.

Although CAI has served well as a research and demonstration tool, it is still in its infancy. According to one estimate[49], several thousand students ranging from elementary schools to university level are receiving a significant portion of their instruction in one subject area under computer control. Hickey [8] and Lekan[36] provide a listing and description of major CAI centers and systems. Hickey[8] lists the university centers, in addition to public school CAI centers and network systems. He reports that over 500 public and private schools now have at least limited CAI capability through time-sharing leased service. In the Stanford project alone, approximately 3000 students were processed daily in 1967-68. Some 6000 students were involved in a CAI program on drill and practice of arithmetic in New York City which is funded under ESEA Title III[10]. This experiment used a RCA Spectra 70/45 large computer that served 192 student terminals located at 15 elementary schools in Manhatten, Bronx and Brooklyn. A similar large-scale CAI system, developed by Philco-Ford, is in operation in the Philadelphia Schools[12]. But except for these few isolated cases, the use of CAI is not extensive and tends to cluster around research centers.

Tables 1 and 2 present a summary of well-known CAI programs in schools and universities directed towards elementary and secondary instruction. Figure 1 shows geographical distribution and locations of CAI centers. CAI activities tend to be clustered around certain research institutions on East and West coasts and the mid-west.

According to a NEA survey[9] conducted in the spring of 1970, 7.7% of all elementary and secondary school teachers who were questioned indicated that their school systems were using CAI. Teachers in the Northeast and Middle states reported the use of computers to a greater extent than did those in Southeast and West. Urban and suburban teachers also indicated a greater use of computers for instruction than did rural ones.

As far as the effectiveness of CBI/CMI is concerned, the number of well-documented comparative data experiments are somewhat limited. The studies that have been made show either superiority or at least equality of computer-

Table 1

CAI ACTIVITIES OF SCHOOLS IN GRADES 1-12 (From Ref. 11)

School District	Hardware used for CAI	Number of Schools with terminals in classrooms for 1968-69 & 1969-70	Type and number of terminals			Level/Number of students receiving instruction		Mode of Instruction and Subject Area				
			CRT	TYPE	TELETYPE	Grades	Number	Drill	Tutorial	Simulation & games	Programing	Combination of modes
Montgomery County, Maryland	IBM 1500 System	3	6	2		2-6	30					AR
		1968-69				9	175					SC
						10-12	160					MA
						11-12	60					C
						12	20					P
		3	12	2		4-6	180					AR
		1969-70				7-9	575					SC
						10-12	1100					MA
						11-12	150					C
						12	60					P
Pontiac, Michigan (Project INDICOM)	RCA 70/35 System	1				3	26	R				
		1968-69				2-6	45	MA				
					32	5	90	EN				
						6	25		SC			
						9	25		EN			
						11	50	MA	MA			
		1				2-3	60	R				
		1969-70				3-4	60		S			
						2-6	400	MA	MA			
						4-6	90	L				
						5-6	60			SC		
					32	6-9	60		SS	SS		
						6-9	30		MU			
						10-11	120	MA	MA			
						10-12	45	RR				
						10-12	100		VE			
						10-12	100		RS			
						11-12	60	L	L			
						12	120		E			
Kansas City, Missouri	IBM 1500 System	1	17	17		7-8	700	MA	MA	MA		
		1968-69						SC	SC	SC		
		1										
		1969-70	same as 1968-69									
Yorktown Heights, New York	IBM 360/40 128K	4				5-8	30		S			
		1968-69		4		6-8	15			E		
						10-11	25				A	
						11	10				M	
		7		7								
		1969-70				1-3	40		R			
						6-8	25			E		
						7-8				E		
Salem, Oregon	IBM 1130 PDP-8 ECP-18	25				9-12					MA	
		1968-69				9-12					BUS	
		25										
		1969-70	same as 1968-69									
Altoona, Pennsylvania	GE 265 Time-Sharing System	17	2		33	6	52					MA
		1968-69				7	1057					MA & SC
						8	1140					MA & SC
						9	1077					MA & SC
						10	1161					MA & SC
						11	1133					MA & SC
						12	1063					MA & SC
		17										
		1969-70	same as 1968-69									
Philadelphia, Pennsylvania	IBM 1500 System	6	40		3	4-6	100			MA		
		1968-69				7-8	50		MA			
	5 Philco-Ford 102's					9-10	500		B			
						9-10	600		R			
		Undetermined 1969-70	undetermined									

Codes for Subject Area

A = Algebra	EN = English	R = Reading	VE = Vocational Education	
AR = Arithmetic	L = Language	RR = Remedial Reading	UN = Undetermined	
B = Biology	M = Meteorology	RS = Research Skills		
BUS = Business	MA = Math	S = Spelling		
C = Chemistry	MU = Music	SC = Science		
E = Economics	P = Physics	SS = Social Studies		

Table 2

CAI ACTIVITIES OF UNIVERSITIES AND R & D CENTERS IN GRADES 1-12 (From Ref. 11)

CENTER	Major Activities: Basic Research	Major Activities: Curriculum Development	Major Activities: Implementation	Major Activities: Teacher Training	Number of Schools Housing Terminals in 1968 - 69	Type and Number of Terminals in Schools	Level/Number of students Receiving Instruction: Grade	Level/Number of students Receiving Instruction: Number	Mode of Instruction and Subject Area	Percent use of Languages	Areas of Interest: Individually Prescribed Instruction	Areas of Interest: Computer-Managed Instruction	Areas of Interest: Administration Problems	Areas of Interest: Teacher Attitudes	Areas of Interest: Cost or Feasibility
University of California at San Francisco	X									Pilot	X		X	X	X
University of California at Irvine		X	X	X						Basic and Lyric		X	X	X	X
Columbia University	X									75% CWTWO 20% APL 5% Other					X
Fairfield University		X								50% CWTWO 50% APL		X			
Florida State University	X				2	8 Teletype	1-6	225	Drill & Practice M & R	90% CWTWO 10% APL		X	X	X	X
Indiana State University	X				1	1 Typewriter	3 4 9-10	45 50 20	Drill & Practice M	FORTRAN	X		X		
University of Minnesota	X									30% CWTWO 5% APL 65% Other					X
Stanford University	X				64	276 Terminals; most are Typewriters	1-3 4-6 7-9	3543 4254 379	Drill & Practice M & R	Assembler Language		X	X	X	X
Texas Christian University				X						60% CWTWO 40% APL			X		
Oakland Community College											X				X
Systems Development Corp.			X			12 Tele-type		58	Tutorial M	PLANIT		X	X		X
Abbreviations									*M=Math R=Reading S=Social Studies P=Physics	*CWTWO= Coursewriter Two APL=A Programing Language					

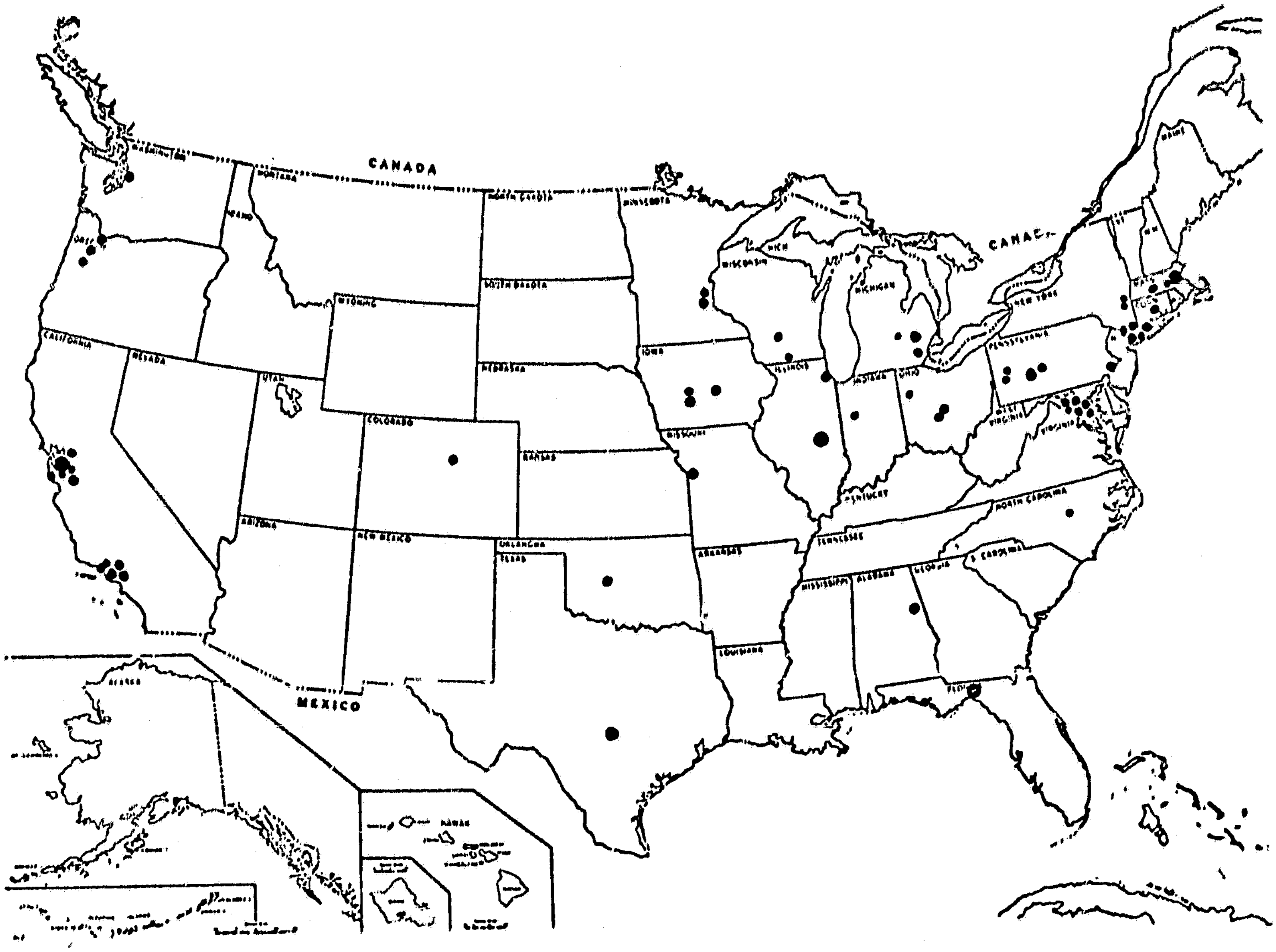

Figure 1. Location and Distribution of Major CAI centers
(Based on Ref. 36)

assisted instruction when compared to conventional methods[10,13,14]. In New York City schools where CAI was designed to complement and support the instruction provided by the teacher, CAI students earned higher gains in most grades with significance differences found in grades 2-3. For evaluation purposes the Metropolitan Achievement Test (MAT) was chosen as it is used extensively by the New York City Board of Education. Higher achievements were noted in spite of the fact that CAI drills were not correlated with the regular curriculum[10]. Diebold cites another interesting example from IBM research[58]. In a CAI course on data processing, student completion-time averaged 22.5 hours as against 30 hours under the classroom lecture method, and the students learning with CAI did 5 per cent better on the final examination than the conventionally trained control group.

A report[15] of the Commission on Education of the National Academy of Engineering (NAE) concerned with CAI and ITV in higher education notes that due to the limitations imposed by the present state-of-the-art, the most successful educational programs (based on CAI) are those with highlystructured or introductory materials. Grayson, a member of the NAE's Commission on Education's Instructional Technology Committee notes in a separate paper[16] that it appears that tutorial programs will be best introduced to instruct in basic courses which have large enrollments and very stable curricula, such as freashman English, introductory language courses, and in science areas, such as biology, physics and chemistry. The NEA survey[9] of elementary and secondary school teachers points out that mathematics was by far the subject most frequency mentioned by teachers having knowledge of CAI in their schools systems. Other subjects listed in which computers are used were English, Business Administration, foreign language, science and social studies.

There is little information available regarding student attitudes towards CAI. The NAE study[15] reports student responses ranging from those enthusiasts who became intrigued with the computer association to those who feel quite negatively towards it because of the alleged dehumanizing effect. However, it is doubtful if these attitudes have any significant effect on student learning, once the mode of instruction is specified. Weiner[10] has pointed out in his evaluation of the New York City CAI program that childern enjoyed working on computers, were very enthusiastic and highly motivated to do well. This was particularly true of childern of average ability. Some slower childern tended to do a great deal of guessing and appeared to be playing games rather than practicing the skills needed to do their class work.

As far as non-academic effects of CAI are concerned, Feldman and Sears[17] exploratory study suggests that CAI critics may have some justification for suggesting that CAI leads to more sedentary, constricted behaviour. On the other hand, claims that CAI individualizes instruction have also been given support in Feldman and Sears study[17], with the finding that correlations between behaviour and achievement are less in the subject in which CAI instruction was given. If it is true that CAI renders achievement less dependent on the classroom behaviour patterns traditionally expected in an academic setting, its contribution to education may indeed be an important one. There remains much work to be done on the psychological aspects of CAI.

It has been pointed out, perhaps correctly, that both the idea of tailoring instruction to fit the specific needs of each individual student and the organization of the conventional time-sharing systems tend to isolate students from needed interaction with other people - interactions that are important from the point of socialization as well as achievements. Undoubtedly, there are some times, some topics, and some students that require isolation but there are also times, courses and students that need interaction. There is no reason why future CAI systems, that permit and even stimulate desirable srudent-to-student interaction, cannot be designed. In a recent paper, Bryan[50] discusses the various ways in which this interaction could be implemented - by terminal sharing; prescribed interactions; terminal-to-terminal processing; simple linking where one terminal can call or 'evesdrop' on another; stored interaction models etc.

As far as university faculty members are concerned, the NAE study[15] reports that the majority are not highly verbal as to their attitudes but often find reasons to bar their speciality from CAI treatment. The extensive programming efforts required to put course material into the CAI format and to get it debugged and ready for use with the computer often discourages administrators and department heads who are aware of the long-term advantages of CAI.

3. ECONOMICS AND COST/EFFECTIVENESS OF CAI: FACTS AND ISSUES

As the NAE report[15] puts it, a serious obstacle to the introduction and use of CAI is the uncertanity associated with its financial implications. The cost of most of the CAI systems in use today is quite high and lies between \$2.60-15 per student hour[18] as compared to the cost of traditionally administered instruction (TAI) which is something like \$0.60 per student hour for elementary and secondary education and \$1.50 per student-hour for higher education (in terms of teacher costs). If CAI is to become economically viable, its cost has to be comparable to that of TAI assuming both are equally effective. Otherwise replacement is unwarranted.

Kopstein and Seidel[19,20] studied the economic aspects of CAI as compared with traditionally administered instruction (TAI). Their study had two basic assumptions underlying it: first, that CAI is a substitute for TAI and not an add-on system, and second, that both CAI and TAI are equally effective. The author is of the opinion that both these assumptions are valid ones. Though today in most cases, CAI has been used to supplement a course or to teach a particular portion of it, there is no reason why it can not be a good substitute for teachers in courses suited to it. However, proctors may be required for the reasons of discipline and assisting students in the use of CAI terminals, as in the case of Florida State University Physics Project under CAI operation[21], and their costs should be added to the CAI operation for evaluation purposes.

Another thing that should be noted is that in industry, if a CAI course reduces the training period substantially, a cost saving can be realized. But the same thing does not hold good in the lock-step, batch-processing education system in this country. Even, if a student finishes a normal year's course in less than a year's time, he is not elevated to the next grade immediately and has to wait till the beginning of next year. During this waiting time, the typical administrator has to provide additional course work for this student which results in increased costs as opposed to reduction that most school boards are seeking. Part of this situation is a result of the babysitting function of the traditional schools between the period when the child is five or six until the individual is deemed able to assume adult responsibilities[22]. The school is expected to keep students "off the streets" during the years of compulsory education. The fact that CAI courses would permit a saving of time will not necessarily result in a cost saving under the existing school structure. It is extremely doubtful that the consequences will be as Gerard[23] describes it:

"There is much reason to believe that we could squeeze as much as three years out of the K to 12 period of school and not leave out anything of worth. In effect, during the 10th, 11th and 12th years students are doing nothing productive in society and are are costing a great deal of money; cutting these years.......is estimated (Machlup) as giving an annual saving of $15 billion. The cost of computerizing the whole education, bringing all the resources - all libraries, and everything else - into a machine-handeable form, building the necessary programs for very rich Socratic tutorial interaction with students at fairly high levels, would be paid for in very few years"[23].

Seidel has come out very strongly, and perhaps very rightly, that to view the developments offered by the innovation of the computer and the application of psychology of learning to instruction from the traditional school house is not appropriate[24]. The criteria for achievement of the student and the concept of the utility of a school need changing if one has to take full advantage of these developments. But these changes, unfortunately or fortunately, can not take place within an educational system bound by the traditional class-room, the traditional teacher, the traditional school day and the traditional administration of the traditional school system. What is needed today is revolution in the conceptual frame-work of education. We have to get away from the "received ideas" of education in a similar fashion in which Hutchins has spoken of the need to change the "received idea" of an economy[25]. We have long laboured under the concept of the class-room as the bench-mark from which education has developed and progressed. All the advances in educational system have left unquestioned the central position of the human classroom teacher as the primary instructional agent and tutor.

But is "man" the best instructional agent to teach man? Can we take this element out of certain portions of the educational process, e.g. the teaching of skills, without dehumanizing the instruction? What would be the sociological, political and other repercussions of this act?

Anderson[60] has suggested separating the technical skills from the human development aspects of education. This process of specialization would make use of the technology for the former and free time and resources for the latter. Whether in fact, such a separation is possible or desirable remains to be evaluated. In the case of CBI, there is reason to believe that the teaching of skills can be effective, provided that the software is effective. Much of the same argument holds for instructional television. However, it should be realized that with CBI we are dealing with an inherently more powerful tool in the sense that CBI can interact and converse with the student and has already demonstrated, in a limited fashion, of being more effective than traditionally administered instruction. For this reason, it is particularly important that pilot CBI experiments be carefully evaluated in terms of their total impact on the student before widespread deployment is contemplated.

As far as the "dehumanization" aspect is concerned, what could be worse than what is depicted in the following sentiment which is heard quite commonly:

"You know, I can remember just one of my teachers doing anything that was really helpful to me in a tutorial way. But for the most part, if I raised difficult questions or if I deviated from the pattern that the teacher thought the class should be following at the time, I was viewed with alarm--I was consideredan uncooperative, unparticipating member of the class."[24]

Whether CAI/CBI is used as a substitute for the traditional teacher for a particular course or courses, partially or totally, the existing school structure is basically incompatible with it. In previous paragraphs, we discussed some of the incompatibilities. Since CAI/CMI is able to manage divergence, how can we let the students proceed through the system in their own pace? A more or less total reorganization of the school system is needed if it were to reap the complete benefits of the computer as an active element in the learning process.The existing concepts of classroom, promotion to higher classes only once a year, year long units of courses, etc. would have to be revised. Many authors have expressed the need for reorganization of the school system but no one has yet offered a satisfactory replacement model. The model has to be realizable through an evolutionary process in face of the massive resistance forces. This is certainly an area where some thinking is needed. There is also a need for an orderly and systematic planning for effective utilization of technology in tomorrow's education system; something similar to the eight-state project on "Designing Education for Future"[59] but on a broader and more intensive scale. However, any more discussions on this topic in this memorandum are beyond its scope and we would leave with our educators, economists and system designers to ponder.

All this has been said to remind the readers of this memorandum of some of the deeper issues inherent in the introduction of a powerful innovation into the educational system and the fallacies and pitfalls that exist in their evaluation. CBI has the potential for bringing about a revolutionary change in education. There is a need for more critical social, cultural and economic studies relating to this new situation and its demands.

Now reverting back to the question of the cost of CAI, we find that under assumption of CAI totally substituting for TAI and being equally effective, Kopstein[19,20] concluded that unless CAI is shown to be atleast ten times less costly than its present (1967) cost, a replacement of TAI by CAI does not seem warranted in elementary and secondary schools. Kopstein[19,20] also concluded that CAI seems to hold advantage over TAI for certain professional and higher instruction, e.g. engineering, medicine, etc.

Kopstein's [19,20] base for the CAI cost evaluation was a 32-terminal system with a computer processor exclusively for CAI purposes, similar to the IBM-1500 system. For six hours of use every day and twenty-two days a month, this accounted for 4,224 hours of basic use at a cost of $14,000 per month, i.e. $3.63 per student hour in hardware costs alone. Kopstein further calculated that if a CAI system of more than 32 terminals is assumed (say 448), the CAI costs could be cut-down to $0.75 per student hour and thus make the CAI a great deal more attract-ve.

At this point, one can take an exception. It is agreed that a 32-terminal setup would be an ideal model for replacing the TAI mode in an average classroom, but it is not necessary for the 32-terminals to have their own exclusive data storage, processor and human computer operator. A shared type operation would save a significant portion of $9000 per month (out of a total of $14,000) that would go into these items at the price of an increase in communication costs. It is the communication cost that will be the critical aspect of such a shared operation (see next section for details on various CAI system configurations) and a dedicated satellite system or reduced rate offerings by a commercial satellite operator may offer cost-savings.

In 1968, Carter and Walker[57] estimated the costs of Computer-Assisted Instruction (CAI). The calculations for the costs were based on the use of two CAI modes: (1) Drill-and-practice mode, and (2) Tutorial mode. They concluded that a drill-and-practice mode built around a central processing unit serving 1,200 students daily through 200 terminals, can be made available at an annual rental of $480,000. For a 100,000 student system, they concluded that a CAI system for drill-and-practice would cost $27 million annually ($20 million for hardware rental, $765,000 for software rental and limited production, and $6 million for other services). For a CAI system built around the tutorial mode of instruction, they concluded that a central processing unit (CPU) serving 210 students daily through 35 terminals could be obtained at an annual rental of $210,000. However, the programs for the tutorial mode were estimated to cost in the neighborhood of $30,000 per hour (of software) as compared to $5,000 for one hour of software for drill-and-practice mode. A rental fee of $210 for one hour of software was estimated by Carter and Walker[57] for the tutorial mode CAI. Conclusion was that for a student system of 100,000, a CAI system with tutorial mode of instruction would cost $72 million annually ($50 million for hardware rental, $5 million for software and $17 million for other services).

Carter and Walker[57] also noted, as Kopstein[19,20] did, that unlike television, the bulk of the CAI cost in each mode is hardware related rather than lesson software related. The only real opportunity for substantial savings, Carter and Walker[57] commented, is in reducing the number of hours the computer is available for each student per day, thus requiring less hardware to serve more children. A reduction from one hour to 15 minutes per day per student and limitation of coverage to half the grades would reduce the costs almost proportionately to about $3.5 million for drill-and-practice mode and $9 million for tutorial mode (for 100,000 student system). On this basis, expansion of CAI to the 16,000 school systems, which represent the bulk of the nation's public school students, were estimated to cost in the range $9-24 billion a year.

It should be noted that Carter and Walker[57] based their cost estimates on decentralized CAI system models - each CPU serving a relatively small number of terminals (200 terminals for drill-and-practice mode and 35 terminals for tutorial mode). They failed to take into account, like Kopstein[19,20], the cost savings offered by large scale CAI systems, such as PLATO IV. In addition, they failed to foresee the dramatic reduction in costs that can be achieved through the intensive use of computer and terminals, both during normal school hours and after school hours. The CAI computer could be used for other purposes, such as administrative data processing for the school and maybe even business data processing for neighborhood businesses which require limited time-shared computer services. After normal school hours, the terminals could be used for adult-education or for continuing education of professionals. This would help in dispersing the hardware costs over a large number of users and increased hours. Also, as Diebold[58] points out, more than 70% of the Carter and Walker estimates[57] could be attributed to the current hardware costs at the time their study was made (1967-68). As we will see later in this section, these costs have been declining rather steadily due to advances in the technology.

There is no reason why CAI system computer could not be used for other purposes too. After all, the basic computer structure for CAI is the same as that of a regular time-shared computer. This question has been addressed by Alpert and Bitzer[6]. It is largely dependent on the size and design specifications of the system. In any multiple-access system it is necessary to set aside some reserve time between individual requests over and above the statistical "average" time of individual student usage in order to avoid long waiting intervals at times of peak loading. In a large computer this reserve time may be substantial. As an example, in the PLATO IV CBI system, the reserve is designed to be of the order of 40 percent of the total available time to assure that the typical waiting time for access to the computer for any student seated at a remote terminal is less than 0.2 seconds. This reserve capacity may be accessed in various ways for time-shared conventional computer programming such as for administrative data processing (ADP).

Bitzer and Skarperdas[26] have made estimates of the cost of a high capacity CAI system that they call PLATO IV. Their design is for a 4,000-terminal system having an initial cost of $13.5 million. Their estimate is that PLATO IV would achieve a cost of approximately $0.34 per student contact-hour. Reduction in cost is based upon several factors such as use of a large time-shared computer, use of algorithms instead of comparing the answers against a long list of prestored answers, and the use of plasma-panels[27] in the display terminals. Plasma panels[27] combine the properties of memory, display and high brightness in a flat structure of potentially inexpensive fabrication. In contrast to the commonly used Cathode Ray Tube (CRT) display on which images must be continually regenerated, the plasma panel retains its own images and responds directly to the digital signals from the computer. Its limitation is that it can only display binary (two-tone) pictures and so far has no capability of displaying grey scale or continuous tone pictures.

MITRE Corporation has been experimenting with a 10,000 terminal, Time-shared Interactive Computer Controlled Educational Television System (TICCET) that they claim would cost between 10¢ to 25¢ per student terminal hour.[31] The heart of the system could be either a Burroughs B-7500 computer with dual 7506 processors and four multiplexers or a CDC-3800 with full Input/Output complement.*

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*Recently the TICCET project has been reorganized.[50] Although still devoted to CAI/CMI, the TICCET system has been redesigned to be small enough to be located at each school, i.e., a change in the design philosophy has taken place - from Nuthman's[31] original proposal of a highly centralized system to a completely decentralized one. In another report, Ohlman[34] has compared the original and the revised TICCET proposals. His conclusion has been that both proposals cost very much the same provided a terminal population of 10,000 terminals is assumed. The author is of the view that the original proposal was discarded due to organizational and sales difficulties in selling a 10,000 terminal system as opposed to 100 terminal systems. The organization for a 10,000 terminal system would transcend traditional school and school board boundaries and it is not difficult to imagine problems in selling such a system. As opposed to this, 100-terminal systems could be rather comfortably sold to moderate and large sized schools. However, it should be noted that the original TICCET system was said to cost 12-37¢ per student terminal-hour and the revised proposal mentions 20-37¢ per student terminal-hour if terminals are used intensively for @2000 hours/year and 40-73¢ if terminals are used normally @100 hour/year (6 hours/day, 175-180 days/year).

One should also take note of the fact that CAI costs are expected to decline with the decline in the cost of the central processing units (CPU), memory and input-output due to developments in electronics. Figure 2a shows Armer's[28] estimates of past costs and those that will prevail in the future if the rate of change remains constant. Note that the vertical axis of the plot is logarithmic; thus the linear curves reflect a constant annual rate of change. The steeper curve shows approximately an order-of-magnitude improvement (decrease) in the cost of computation every four years equivalent to an annual improvement in effectiveness per dollar of 80%. This is intended to refer only to the capability of the central processor plus an associated memory unit. The flatter curve shows the relatively minor improvement in the cost of typewriters (intended to represent the interactive interface with man). Zeidler et al[52] have also noted in a SRI study prepared for the FCC that both hardware and software costs have shown a decline of 25% per year, where hardware cost is taken as the cost per standard computation and software cost is per "phrase". Sisson[30] has a somewhat similar prediction to make:

> "In the next five to ten years...arithmetic and logic processing components will be developed which can be produced at significantly lower cost than present units. A basic gating unit which costs several dollars in 1955 and is now 50¢ or so will go to 3-5¢. This three fold decrease will result from the use of integrated circuitry."[30]

Mayne[53] predicts a substantial drop in memory costs (Figure 2b) through the advent of Large Scale Integration (LSI), a recent phenomenon. Though the extent of past progress is essentially an empirical issue and a prediction of the future by extending the trend line is highly questionable, Armer's[28] and Mayne's[53] studies do provide some idea about the possible reduction in the CPU and storage costs. We can look forward to more substantial reductions in CAI costs, a major portion of which is accountable to the hardware segment of the system, thus making it much more attractive economically.

The total cost of any CAI/CMI system is comprised of the costs associated with each of its four major components:

(1) Processing Units and associated memory
(2) Terminals or Input/Output devices
(3) Software, and
(4) Communications.

In highly centralized CAI/CMI systems, such as PLATO IV, the original TICCET proposal and the Stanford CAI system, the economic viability of the system is critically dependent on the communication costs (see Section 4). While the cost of computers and other noncommunication components of the CAI/CMI system has been dropping rather steadily, as we discussed earlier in this section, the cost of a telephone line appears to have been approximately constant over the past decade.[48] If this trend continues, eventually the communications cost will become the dominant cost component of centralized CAI/CMI systems and perhaps the limiting factor in the reduction of CAI/CMI service costs for small, rural and not-so-affluent schools.

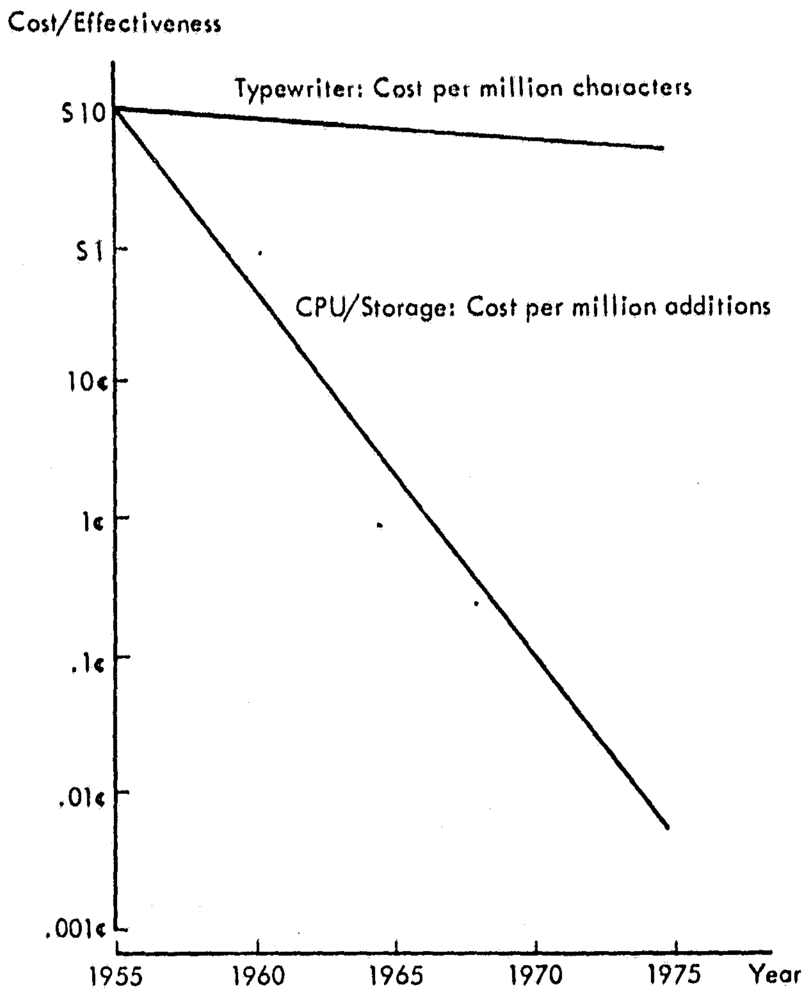

Figure 2a. <u>Estimated Trends in Cost-Effectiveness</u> (from Ref. 28)

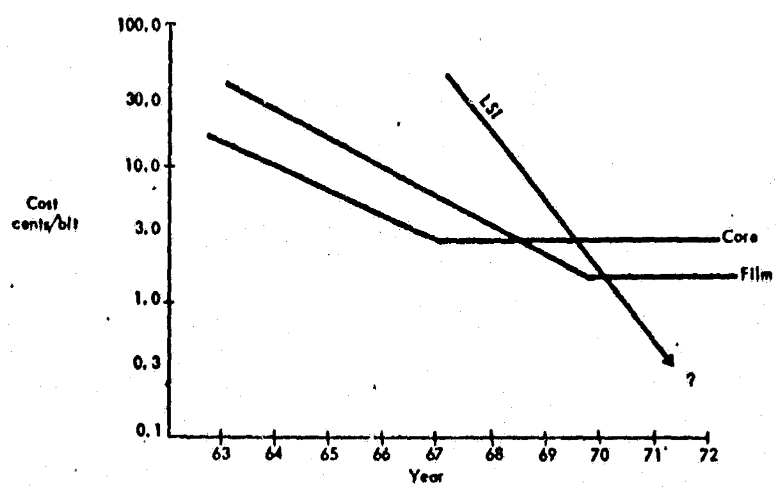

Figure 2b. <u>Comparative Memory Costs</u> (from Ref. 53)

SRI's projection of the future trend of telephone line costs shows that the cost of a telephone line will very much stay constant for the coming decade.[52] This is a somewhat surprising result, when the advances in microwave technology, coaxial lines, and satellite long-haul communications systems that have taken place in the last decade are considered. Such long-haul systems have indeed dropped the long-haul portion of the telephone line cost and further reductions are expected when domestic satellite and millimeter waveguide services are introduced. But the problem is that over 80% of the cost, even of long-distance calls, is in the local telephone plant, and there is very little prospect for the significant cost reduction here.

The commercial communication system was originally built for transmitting analog signals, such as telephone and television. Digital signals, a relatively recent phenomenon, have been accommodated by improvements which were made to be compatible with existing communication network. A voice-grade line has a nominal bandwidth of 4kHz. While in theory, very high orders of bit transfer rates, or line speeds, can be obtained on so-called voice grade lines, in practical applications transmission rates are severely limited due to the line filter. On unconditioned telephone lines, line-rate is limited to 2000-3600 bits/sec. Bell and a new company, Datran, are planning digital networks to serve specialized data-communication needs and it remains to be seen what kind of cost-reductions they will be able to offer.[56]

Current R & D is being addressed to a number of problem areas to make CAI systems more economical. Areas being addressed are: system design and terminal capability, programming languages and procedures, pedagogical techniques in relation to various subject matter areas, and problems of operational use. To achieve good cost-effectiveness, a thorough and well conceived exploitation of the following system capabilities unique to a computer based system is warranted:

- means of input and display which permit flexible man-machine communication more economically,
- capability to process and respond to messages written in natural language,
- capability to rapidly evaluate complex mathematical functions,
- capability to record, analyze and summarize student performance data, and
- capability to administer programs of instruction in which flow of control is contingent on variety of program parameters and indices of performance.

So far we have been primarily concerned with the hardware costs and investigated some large-scale CAI system proposals like TICCET and PLATO-IV which compare very well with TAI costs. Though hardware cost is the dominant portion of CAI costs, the costs of procuring or renting suitable instructional programs can not be ignored. Cost of writing and debugging an hour's worth of instructional material may be any where between $81 and $30,000 per student hour, depending upon the mode of operation, tutorial or drill-and-practice.[32, 57] It should be remembered that the software is the heart of the CAI system and its effectiveness very much depends upon the quality of software in use. Feldhausen[18] has expressed a need for more exciting and effective programming. One could safely assume an hour's worth of good CAI instructional material (for drill-and-practice) prepared by interdisciplinary teams of psychologists, subject experts and programmers to cost $5,000-$8,000. If this program is developed exclusively for a school with an average class strength of 32 pupils, the software cost alone would be something like $31-50 per student hour for a program life of five years. For tutorial type software, the costs will be even higher. This points out to the need for economies of scale, i.e., resorting to mass distribution and preparation of CAI programs. However, mass distribution would require certain steps in the area of the compatibility of computers, input/output devices and programs. Today there is a multiplicity of CAI languages and many instructional programs are even written in assembly languages. The problem of incompatibility is not unique to CAI. It is true for the newly developing electronic video recorders and cassette players. However, this situation would have to be resolved if the cost of preparing good CAI material is to be justified and CAI systems are to compare favorably with TAI in cost.

Any further description of the state-of-the-art, or issues in these areas is beyond the scope of this memorandum which is primarily concerned with the exploration of the long-distance telecommunications aspects of CAI/CMI. Comprehensive treatments on interactive communication devices/ interfaces can be found in a recent book by Meadow[33] and an article by Brick.[51] Ohlman[34] provides a brief description and comparison of various display devices. Complete bibliography on topics related to CAI, specially information on operational systems and CAI languages, can be found in reports by Zinn[35], Hickey[8] and Lekan[36].

4. CAI SYSTEM CONFIGURATIONS AND TELECOMMUNICATIONS:

There are three quite different lines along which CAI systems are being developed and implemented.[14, 26, 37] One, a highly decentralized approach, is that of a low-cost computer serving a small number of student terminals (5-20) at a single location. On the other extreme would be a highly centralized system with a single high capacity computer to serve a large number (several hundred or more) of terminals over a broad geographical region. In between these two extremes, there can be a system in which several terminals in every school form a sort of cluster and these clusters have their own limited mass storage and processors. At the same time, these clusters are tied to a common single processor whose hardware and software capabilities are shared by the various connected clusters. Cluster operation is fairly independent to some degree, but nevertheless dependent upon the hardware and software residing in the central processor. Operation of the clusters over an extended period of time requires availability of, and participation by the central facility.*

Figures 3-5 show the schematics of the three types of CAI systems. An example of the totally decentralized type of system would be the CAI system under production at Computer Curriculum Corporation (CCC) of Palo Alto, California.[14] It is an eight terminal system that will be used for drill and practice in arithmetic (grades 1-8). On the other end are versatile, large CAI systems such as PLATO IV[26] which will have 4000 terminals and would have an initial cost of $13.5 million as opposed to $30,000-40,000 for CCC type systems. The CAI system operated by the Philadelphia School System belongs to the third category of combined central and cluster processing.

The centralized system approach can lead to economies in the allocation of mass storage facilities especially when course material is common to more than one school or school system. In a centralized system, no mass storage capacity is required as each terminal is capable of interacting independently with the central facility. As far as systems based on combined central and cluster processing are concerned, each cluster requires only that sufficient mass storage capacity be available at the cluster location to maintain its immediate needs of lesson presentation as dictated by student and student-terminal characteristics. The cluster calls for additional material to be transmitted from the central facility prior to the actual need and in accordance with daily schedules prepared in advance. The curriculum library for all clusters, as it is common, is maintained at the central facility through a combination of serial access and random storage devices. At the cluster, the quantity of storage on-line is sufficient to supply course material to n-terminals for one, two, or more hours. In a completely decentralized system, total

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*Clark and Molnar[54] of the Computer Systems Laboratory of Washington University are working on a Broadcast Information Processing Concept which seems to be particularly attractive from the view-point of a satellite-CAI/CMI service for rural, small and not-so-affluent schools which, for economic reasons, can not justify their own CAI setup. The main problem in the satellite-CAI/CMI service is that of providing individual terminals an access to the satellite for return-connection to the central computer. Clark and Molnar[54] conceive of a system in which fixed programs or data is "broadcast" from a central "transmitter" simultaneously to any number of "receivers" which carry out computations. The transmitter repeatedly broadcasts all the information in its stored library, and only one-way communication from the transmitter to the receiver is required. The power of the scheme lies in the fact that the continuously available broadcast information makes it possible for large numbers of very small receivers with limited local working storage to do very complex and large jobs at low cost. This scheme has been implemented using a small on-line computer LINC for various purposes including hospital intensive care monitoring and computer-administered teaching. In a forthcoming memorandum, the author would attempt to study the implications of this concept in greater details.

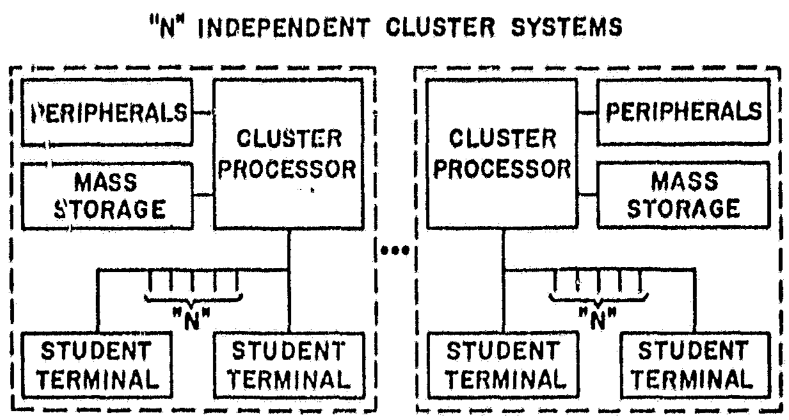

Figure 3. Decentralized CAI System

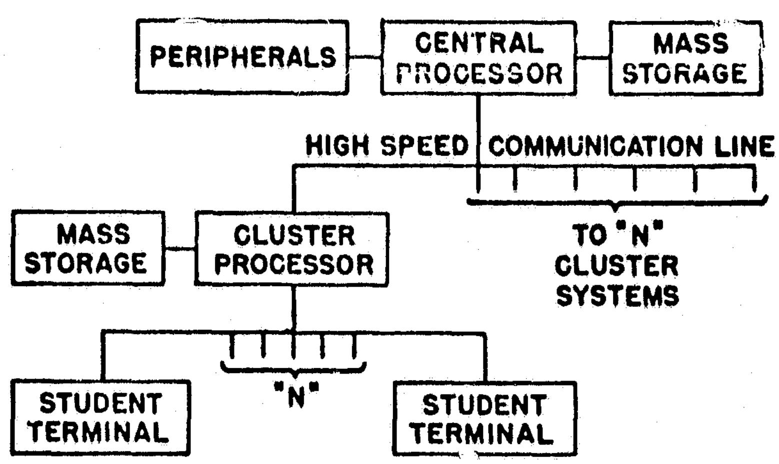

Figure 4. Combined Central-Cluster Operation

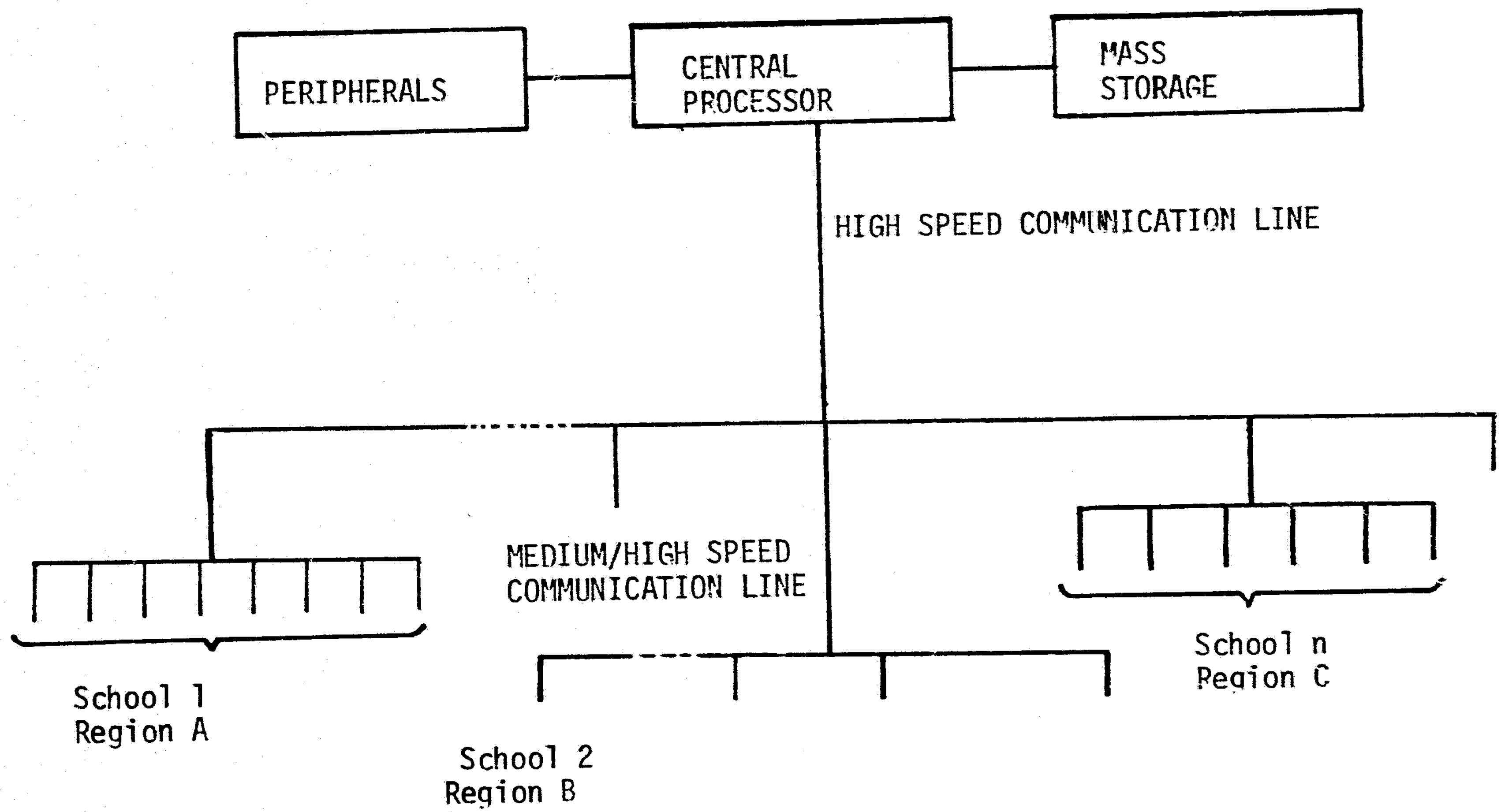

FIGURE 5. A HIGHLY CENTRALIZED CAI SYSTEM

curriculum would have to be maintained at each cluster location in addition to the cost multiplication for various peripheral devices at each cluster, which under the centralized system are shared by all clusters.

Interactive telecommunications requirements of completely decentralized CAI/CMI systems are entirely local, i.e., between the terminals and the processor which are located within the same physical facility. Programs could be distributed either by transporting magnetic tapes and discs, as the case may be, or by wideband telecommunications depending upon the requirements. CAI/CMI systems, based upon combined central and cluster processing, require wideband communication links between the central processor and mass storage and the cluster processor and mass storage. Local telecommunications requirements for linking terminals with the cluster processor are the same as in the case of completely decentralized systems. Totally centralized CAI/CMI systems have altogether a different requirement. Here the critical aspect of the economic viability is the cost of communication. Incoming and outgoing information for a number of terminals located in a single school can be multiplexed and transmitted together.

Figure 6 shows the System Configuration of the Stanford University CAI system and gives a good idea of the long-distance telecommunications that is involved in a centralized CAI system. When Kentucky Schools were receiving CAI instruction through the Stanford System, system operation was a combined central and cluster processing type. A PDP-8 computer with a 4K (12 bit) memory was used as a cluster processor in Kentucky.

Speed of incoming data (from processor to the individual terminal) may be anywhere between 14 bits/second to 200 kilobits/second depending upon whether the information being transmitted is pictorial, voice, alphanumeric or terminal address. In a large scale system like TICCET, it is estimated that, during any one second, 10 percent of the frames transmitted would be pictorial or voice (200,000 bits), and 90 percent would be alphanumeric (10,000 bits) in addition to 1,000 terminal addresses (14 bits) under the assumption the average frame change would be something like 10 seconds. This adds up to a 30 megabits/second.[31] As opposed to this, the outgoing data rate is trivial (20 bits/second per terminal). For a 100-terminal setup, it would be 2 kilobits/second and could be easily accommodated on a Data-Phone line if a data concentrator is used. In the PLATO IV system, the peak data rate from the computer to each student terminal is limited to 1.2 kilobits/second and thus for 4000 terminals, the worst case data rate is about 4.8 megabits/second. A data rate of 60 bits/second is anticipated for transmitting the student keyset information back to the main computer center.[26]

Extending CAI/CMI services to isolated, not-so-affluent and small rural schools is a very difficult but important task. Large urban schools/school systems can either have a completely centralized CAI system like PLATO IV, TICCET etc., or if the school system population is very large and beyond the capability of a single CAI system (230,000), a partially decentralized system based on central and cluster processing to minimize the system cost by cutting down redundant mass storage requirements. Affluent suburban schools will probably go for a completely self-contained unit such as the one being produced by Computer Curriculum Corporation of Palo Alto[14] or

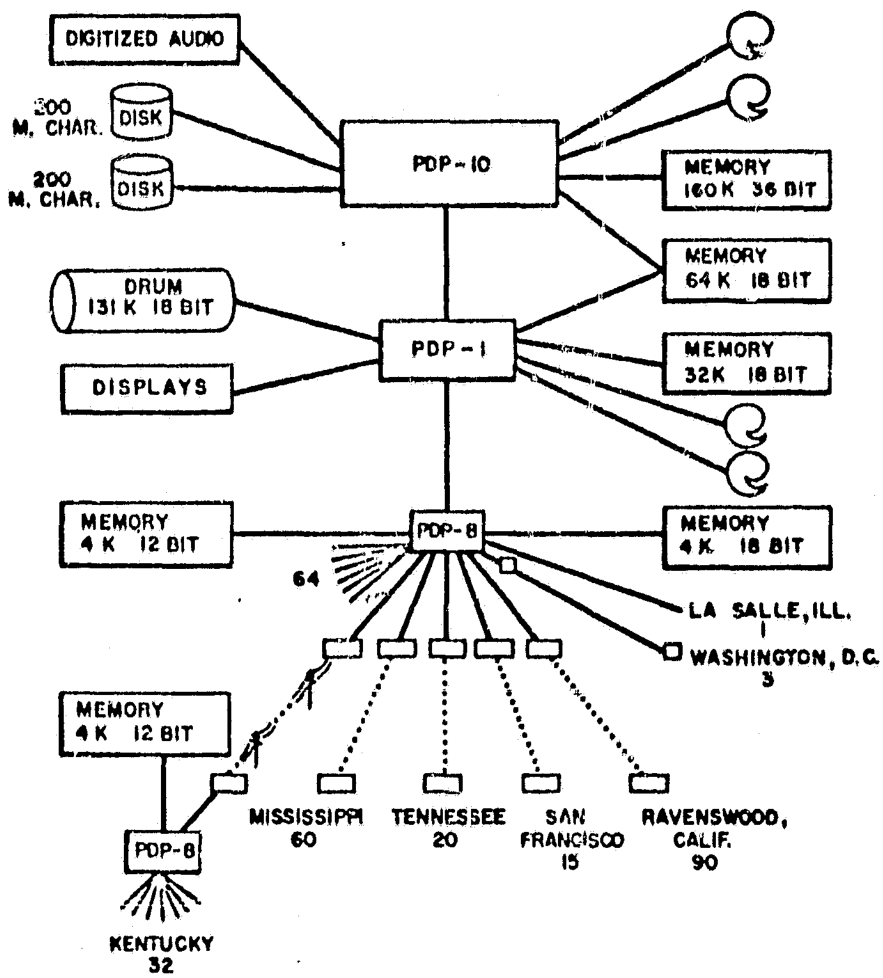

Figure 6. Stanford University CAI System

IBM 1500 system. For rural schools, one will have to devise ways in which the hardware costs could be shared by a larger population so that CAI costs for rural areas are comparable to those in urban and suburban schools with larger student density. This is where one perhaps can make a breakthrough by the use of communications satellites because the communication cost is independent of distances up to 10,000 miles or so and could be made small by having a specially designed satellite for delivering signals to a low cost and small diameter antenna headend ($1500-3000). Many services, such as remote batch processing of administrative and educational data, ITV and PTV, remote electronic browsing etc., sharing the same terminal. No insurmountable technical problems are foreseen. On May 18, 1970, Stanford University conducted a successful experiment by tying nine terminals at a single elementary school usually served by a phone line by relaying the signal through NASA's ATS-1 experimental satellite.[14, 45]

Today, when people talk about educational/instructional applications of communications satellites, what they generally have in mind is ETV/ITV signal distribution for rebroadcast and/or community reception directly from the satellite. Very few people have discussed the satellite-computer combination to any great detail. Sheppard[41] has proposed an instructional communications satellite system for the United States which allows each state to have one data-terminal (CAI) for every twenty five students at a cost of $8.08 per student per year (in hardware costs alone). Even if one triples this figure to account for software and maintenance, Sheppard claims that $25 per student per year is still quite reasonable in terms of typical expenditure per student per year. A typical expenditure per student in public elementary and secondary schools is $783 when only current expenditure is accounted for.[42]

Krause[43], in a document prepared for the MCI-Lockheed Satellite Corporation, has dwelled into various computer applications for schools in connection with the MCI-Lockheed proposal for a domestic satellite system, which offers five transponders in their 48-transponder satellite to educational users. He rightly points out that the large initial costs of CAI programs decline dramatically on a per-student basis when sizable markets can be assembled by low-cost, long-distance telecommunications. Larger markets for a computer program can, of course, be assembled by sending the program on tape and cards to other compatible computers. As was mentioned in the earlier section, this method of operation often is complicated by differences between computers and by difficulties in uniformly incorporating changes into programs at different computers. Such translations or changes also increase the cost of the program. A program that costs $500,000 to develop might provide 100 hours of instruction, averaging $5,000 per hour. If that program can be used by 500,000 students during its useful life of few years, Krause[43] argues, the cost per student-hour is only 1¢. To achieve this size of audience (≈500,000) to make CAI economically viable, low-cost long-distance telecommunications have an important role to play. As we discussed in an earlier section on costs, CAI/CMI and other computer based instructional technologies have a very heavy fixed cost base and the economic viability of these systems critically depends on assemblying at least a critical population. In urban areas, there would be no difficulty in assemblying the critical mass locally. But in small, remote, rural, isolated or relatively less affluent communities, this would be a major problem and some means of low-cost, long-distance telecommunications facility would be needed to link schools in these areas, in many cases urban as well as suburban ones, too, to a common and shared central CAI computer facility.

The next question that comes up is how can we provide low-cost long-distance telecommunications facility to make the CAI systems discussed earlier economically viable. What system and media should we choose:

(1) AT&T and the Bell system

(2) specialized common carriers

(3) the free or reduced rate provisions on the proposed commercial multi-purpose satellite systems, or

(4) should we establish a dedicated educational/instructional satellite service to serve variety of needs ranging from CAI to ITV and computer networking.

We will leave this question for the Systems Synthesis phase of the work. However, some observations could be made at this stage.

Future telecommunications requirements for CAI systems are extremely difficult to estimate due to a large number of uncertainties involved, such as the three distinct ways in which CAI/CBI systems could develop (each with its own set of telecommunications requirements), the degree of CAI penetration that could be achieved, the mode of CAI usage--reinforcement or complete substitution of teachers--and the money supply. Currently we have a study investigating the nature of the educational production function underway. When completed it will provide certain guide lines for obtaining the same educational results with different sets of ingredients that go into the education of a student--teachers, buildings, educational media, etc. Then, given estimates of the money available to education, say for 1975 and 1980, one could estimate the near optimal or optimal strategy for education and the fraction of the funding that would go to educational media and technology. Such a monetary constraint would have to be taken into account, if any realistic analysis is to be made.

In addition to these uncertainties, there are some more, such as what kind of human interface would be employed--teletypewriter, teletype, light pen, cathode-ray-tube, plasma panel, etc. This would influence the data-rates that the telecommunications channels would be required to handle. However, in this area one could make certain assumption: that a CRT or plasma panel interface with a clear image is the minimum essential, that still-pictures (motionless) would be acceptable and that a keyset would be used for data-entry in most of the applications. In some graphical applications, terminals should be able to handle light-pens. Purely typewriter or teletype terminals are less attractive ways of communicating with a student and they limit the range of things that could be taught using the same computer processor. In spite of the continual replenishment problem of the CRT terminal, it seems to be more appropriate at this time than the plasma panel due to its gray scale handling capability. However, work is continuing on providing multi-tone pictures on plasma panels and if successful, plasma panels would be a welcome substitute for CRTs. The data rate requirements for a single terminal could be safely assumed to be 1.5-2 kilobits/second (from the CPU to the terminal) and 15-50 bits/second from the terminal to the CPU depending upon the particular design.

Once we know certain estimated penetration bounds of educational technology in the future, we could divide the technology input up among various different media--television, CAI/CBI/CMI, teaching machines, etc., and look into the geographical distribution of these. At that point we will undertake the evaluation of the suitable transmission media and system.

The basic networking requirements for the centralized CAI/CMI systems could be classified in multipoint-to-point and point-to-multipoint categories. A single switchboard in the sky, a satellite, has certain advantages for this kind of networking and offers certain distinct flexibilities. Geographical rearrangement of CAI terminals could be handled very easily, including new additions in the local cluster, as satellite provides a point-to-area service as opposed to the point-to-point service that is inherent in the terrestrial plant. Roof-top earth stations can be given access to the central computer, or an information resources center or to other clusters for teleconferencing or other purposes on a single channel per carrier basis either using FDMA/FM* or FDMA/PCM-PSK** mode.

However, it should be noted that the main problem in the use of a satellite link for data transmission lies in the increased propagation time (≈0.26 seconds-one way)[44]. Many existing data modems with transmission error control would be severely reduced in efficiency by the delay in receiving the return signal. New terminals can be designed which do give high-transmission efficiency, changing the logic of error control. The response to the transmitting machine saying whether or not data message or block was received correctly will not arrive until 0.52 seconds or more after the block was sent. Several blocks may be sent in this half second, even if only a voice channel is being used. The transmitting machine must therefore have sufficient storage to retain the blocks until their response is received, so that it can transmit them again if necessary. This delay slows down the fast response that a CPU is able of generating in case of a real-time application. For CAI applications, it would be inconsequential.

A recent paper by Jamison[45] indicates that even with today's satellite technology, for most purposes there is a clear scientific advantage to satellites for reaching the rural population. He faces the same problem in deriving a cost minimization that we have been discussing so far; that is, absence of exact information on the number and geographical distribution of the terminals involved in a CAI system, as well as the location of the central computer. He then hypothesizes two models--one using satellites and the other using commercial telephone systems.

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*Frequency Division Multiple Access/Frequency Modulation.

**Frequency Division Multiple Access/Pulse Code Modulation-Phase Shift Keying.

Assumptions, inherent in both models, are that the typical school that is going to use CAI/CMI is a reasonably small school and requires on the average eight terminals. For the commercial telephone line, the cost is based on projected cost figures for 1975. The space segment costs are based on the assumption of leasing two transponders of a satellite comparable to Hughes' HS-333[46] with an annual cost of $375,000 per transponder. The author also takes a lower bound of $0 per transponder, corresponding to any possible free rides on the commercial satellites, similar to that proposed by the MCI-Lockheed Satellite Corporation for the first five years in their domestic satellite filing. Jamison's study[45] also presents trade-offs of antenna diameter, number of channels, system noise temperature, desired quality, threshold extension for a transponder output of 7 dbw (5 watts) for both outbound and return link through the satellite and a satellite antenna gain of 26 dB. Ground stations are contemplated having a 12-foot parabolic dish suitable for transmission at 6-GHz and reception at 2.5-GHz at a cost in the range of $8,000-11,000.* Figure 7 compares satellite with commercial phone system costs as a function of D, the distance (air-flight distance) between the central facility and the cluster or individual terminal for several values of the ground station cost. Comparisons are made for two different populations (750 and 1250) of teletype terminals connected with the central computer. Comparisons are based on the assumption of the annual satellite cost of $150,000 as a "best estimate" between the upper bound of $375,000 and a lower bound of 0.

Jamison's[45] comparison clearly shows the superiority of the use of satellite transmission for providing CAI/CMI services to small, isolated and poor rural areas which can not afford a similar service on an unshared basis. However, there are a few assumptions inherent in his model which need further thinking. His satellite model assumes the availability of two transponders on a domestic multi-purpose satellite for the "best" estimate of $150,000 annually. We believe this cost figure as rather unrealistic. COMSAT-AT&T joint filing[47] to the FCC for a domestic satellite system envisages 24-transponder satellites for which AT&T will have to pay $1.037 million per month. Previously, the system was supposed to have only two active satellites, AT&T was supposed to pay $1.23 million/month. This comes to a cost of $615,000 per transponder per year. To lease the services of two transponders, one would have to pay at least $1.23 million per year, exclusive of earth station facilities unless some reduced rate provision are made by AT&T. Though today MCI-Lockheed Satellite Corporation[43] plans to provide five free channels for educational users, nobody knows what reduced rates they would charge five years later when they have picked up users for the channel capacity that would go unused today. Besides, right now they are interested in showing public dividends as they are competing for a non-depleting but scarce resource of orbital slots and operational frequency.

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*6-GHz transmission to a satellite with a 12-foot dish is incompatible with certain recommendations for the effective utilization of the geostationary orbit.[61] An exclusive allocation in the neighborhood of 2-GHz (S-Band) would be very desirable for satellite-to-earth link as well as earth-to-spacelink for educational/instructional usage involving small antennas (<30 foot diameter).

In addition, one has to keep in mind that all of the domestic filings envisage multi-purpose satellites to operate with relatively large-diameter antennae. The power flux density reaching earth is limited by a CCIR recommendation so as to avoid any harmful interference to terrestrial microwave relay systems operating in the same band. Even if the MCI-Lockheed or any other system that finally materializes agrees to give a free ride or charge reduced rates for educational/instructional transmissions through the satellite, the investment in ground stations would be substantially larger than what could be achieved with the existing technology by having a satellite which is suited to the educational/instructional uses and operates in frequency bands different than 4 and 6-GHz. If all the educational users and resource managers could be pooled together, the author is of the opinion that a satellite system could be devised to meet multiple educational needs, all funnelled through a common satellite and received through a common terminal that would be substantially cheaper than the earth-stations operating in 4 and 6-GHz shared bands with the commercial multi-purpose satellites. Like any other communication system design, the optimal or minimum cost design would be the one which would lower the cost of the ground-terminals which will eventually have large populations (≈110,000 if each school has a roof-top terminal).

The author does not think that it would be possible to procure satellite borne transponders at a unit cost of $75,000 per year as accepted by Jamison for the purposes of his calculations. A cost figure in the range of $210,000-180,000 per year per transponder seems to be reasonable for a relatively higher power satellite (40-55 dBw e.i.r.p.) having something like 24 transponders (ten in 2.5-GHz band and fourteen in 12-GHz band) and deployable and oriented solar cell array with a satellite mean time to failure (MTTF) of 7-8 years. However, one should remember that the transponders would be in use mostly during the school hours (5 days a week, 6 hours a day and 180-185 days a year) and perhaps during evening hours for adult and continuing education to disperse the hardware cost of the CAI system over a larger mass of users. In the late night hours and other times when CAI system is not being used, transponders could be switched back to other services. Unfortunately, the peak hours or the busy hours for the CAI would be the same as other services and if the satellite were a commercial one, the pricing would be done so as to extract the major portion of the investment plus profits during the busy periods. Similarly, here it would not be justifiable to price the transponder to have equal load 24 hours a day and seven days a week and say that if CAI is used for 8 hours a day and five days a week, one will have to pay only about 24% of the actual transponder cost. For our calculation, we could safely assume a cost of $150,000 per transponder per year for CAI use.

For the kind of dedicated satellite described above, the earth station cost (antenna, preamplifier, downconverter, demodulator and a 50-75 watt transmitter) for mass production is expected to cost somewhere in the range of $1000-2300. It is also to be noted that the receive section of the terminal could be shared to bring in other services like ITV and ETV etc. and the return channel could also be shared for the purposes of remote electronic browsing, remote information search, and in certain isolated areas even for the purposes of remote medical diagnosis. So, CAI/CMI's share of the earth-terminal cost could be taken as $1,500 on the assumption that these earth-terminals are manufactured in large quantities (>20,000 units).

Even with these numbers, satellites would be more attractive than commercial telephone plant as shown in Figures 8a and 8b for connections between the central computer facility and terminals which are longer than 600 miles (air mileage) for 750 teletypewriter terminals and distances above 400 miles for a system having a terminal population of 1250 teletype terminals.

Jamison's model[45] is based upon the assumption that teletype terminals are used which have low input/output rate. If one plans to use a motionless CRT or plasma panel display (line drawings and alphanumeric) leading to a higher data rate per terminal (1.2-2 kilobits/second), a system with a large number of terminals such as PLATO IV of University of Illinois which will have 4,000 terminals, and if a wide range of cluster population is assumed (say, 1-40) so that multiplexed data rate for these populations does not always conform to certain channel capacities available from the commercial telephone network (see Table 3), the cost savings offered by the satellite would be much more pronounced and satellite transmission is expected to become efficient for interconnection lengths of 150-200 miles and over.*

We plan to give a detailed look to the question of comparative costs when all educational requirements are assembled and categorized. Instead of treating each educational telecommunications media individually, we plan to give them a unified look.

In another memorandum we would explore the possibility of using NASA's experimental satellites ATS-F/G, joint US-Canada experimental satellite or a hypothetical HEW-NASA satellite as a stepping stone towards an operational educational telecommunications system. Today, when money supply has become scarce, no one is going to buy a new innovation unless it is proved to be more cost/effective than the techniques/media they have been using. Neither CAI or ITV has yet proved itself to be cost/effective though there is no reason why they could not be proved so if proper models are used, both in terms of hardware and organization. If these innovations are to be diffused, their capabilities would have to be demonstrated, not only in terms of "improved quality of the product" but in terms of costs also. And this clearly calls for certain experimental demonstrations to serve both the purposes of demonstration and to check and improve the theoretical models of large-scale systems.

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*The CBI model that the author conceives as being more versatile and cost-effective is substantially different than the system in use at Stanford University (Figure 6) on which Jamison[45] bases his model. The model that author has in mind uses CRT or Plasma Panel display along with a key-set for data-entry in place of a typewriter or teletype. PLATO IV system, under development at the University of Illinois, Urbana, is closer to author's model.

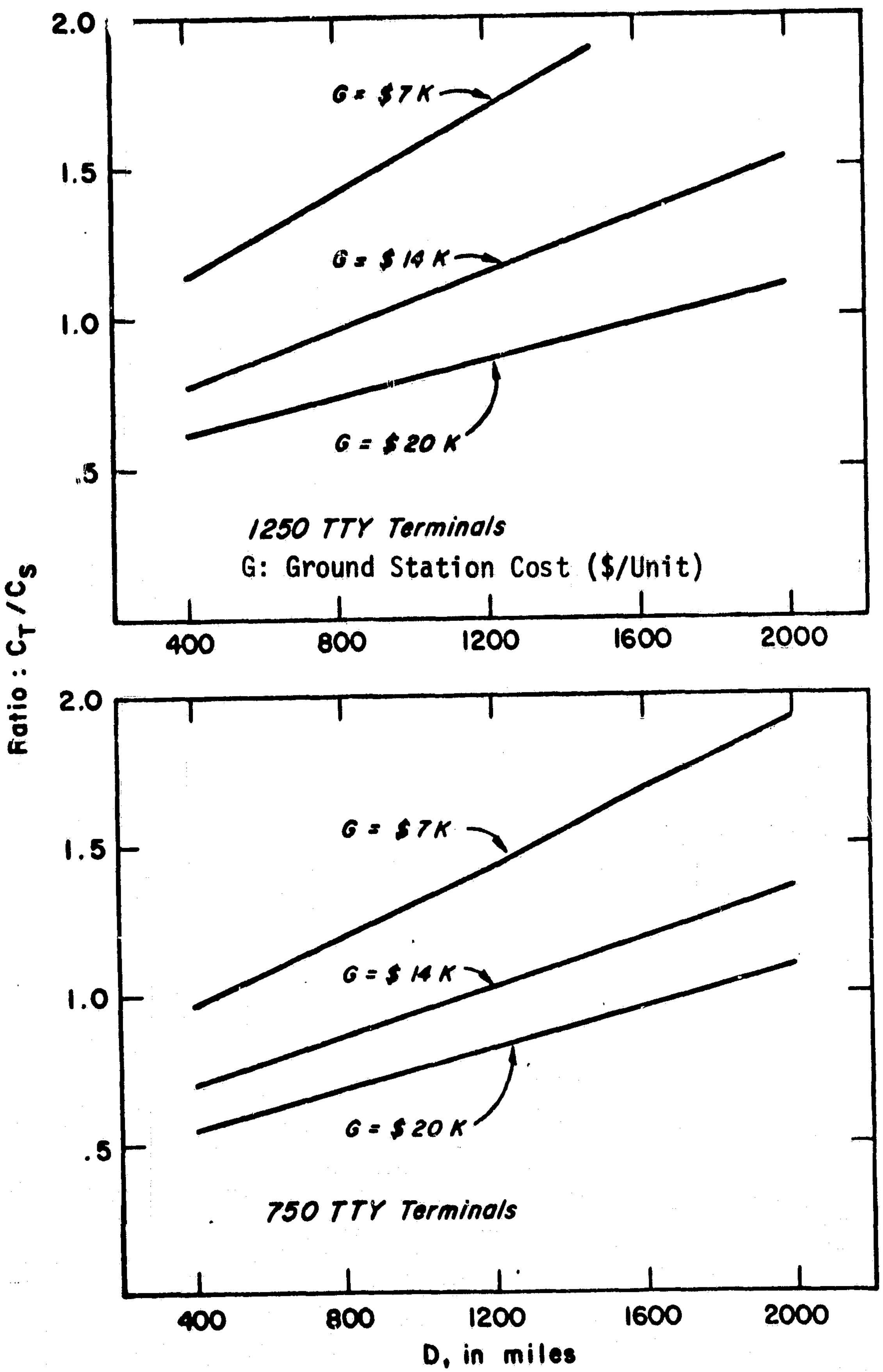

Figure 7. Ratio of Commercial Phone to Satellite System Costs for Jamison's Model (from Ref. 45)

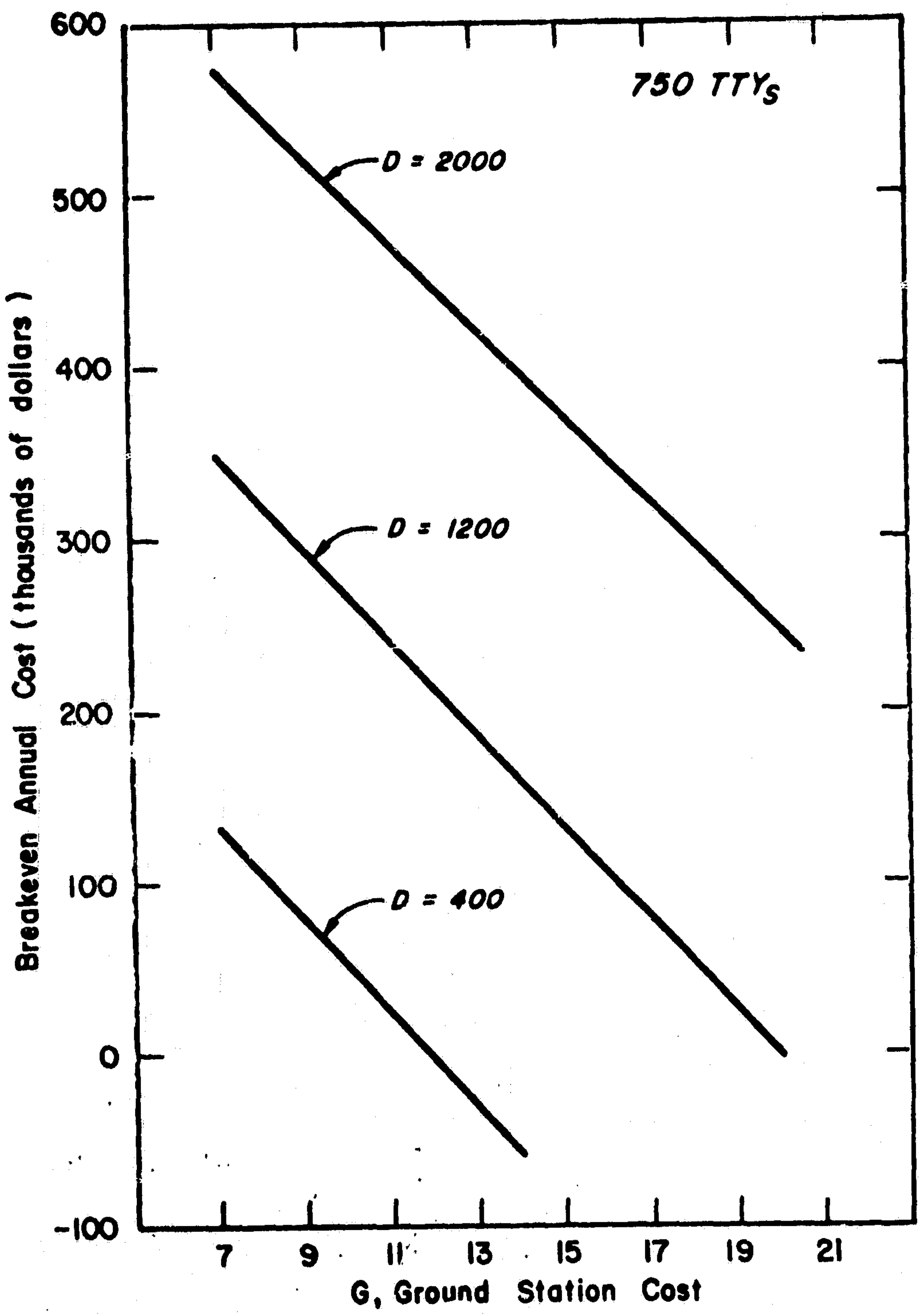

Figure 8a. Breakeven Annual Satellite Cost for Jamison's Model (from Ref.45)

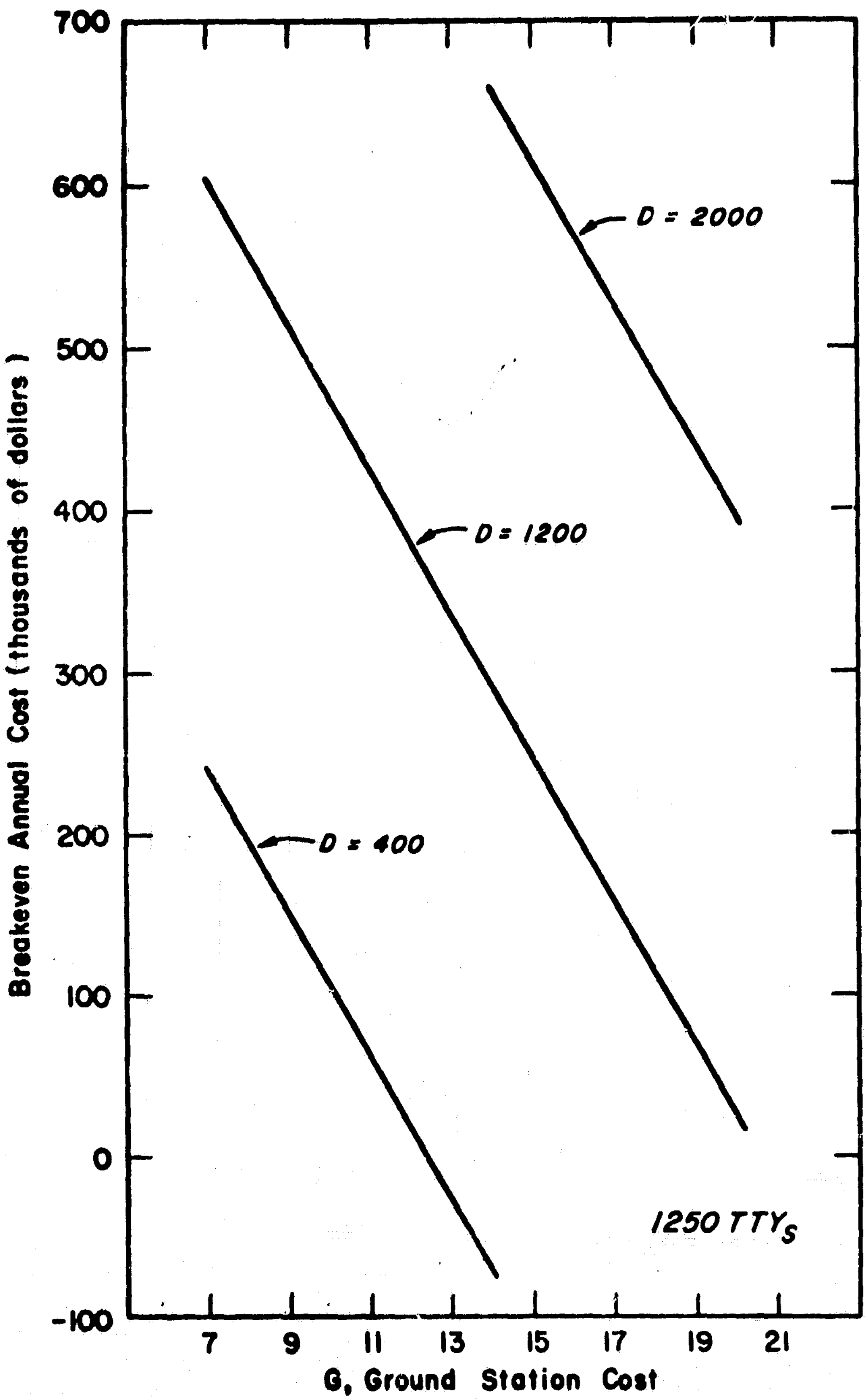

Figure 8b. Breakeven Annual Satellite Cost for Jamison's Model (from Ref. 45)

Table 3

COMMON COMMUNICATION LINES AND TRANSMISSION SPEEDS IN USE TODAY

	Speed (bits/second)	AT&T	Western Union	Half-Duplex or Full-Duplex	Leased or Switched
Subvoice Level	45	1002	Class A	FDX/HDX	L
	55	1002	Class B	FDX/HDX	L
	75	1005	Class C	FDX/HDX	L
	75		Telex	FDX/HDX	S
	150	1006		FDX	L
	150	TWX-CE			S
	180		Class D	FDX/HDX	
Voice Grade	0-300	Data-Phone		FDX	S
	600		Broadband Exchange, Schedule 1	FDX	S
	0-1200	Data-Phone		HDX	S
	1200	3002	Class G	FDX/HDX	L
	1200		Broadband Exchange, Schedule 2	FDX	S
	1400	3002 Plus C1 Conditioning	Class E	FDX/HDX	L
	2000	Data-Phone		HDX	S
	2400	3002 Plus C2 Conditioning	Class F	FDX/HDX	L
	4800	3002 Plus C4 Conditioning	Class H	FDX/HDX	L
Wideband	19,200	8803		FDX	L
	40,800	8801	Wideband Channel	FDX	L
	40,800	Data-Phone-50		FDX	S
	105,000	5700	Telpak C	FDX	L
	230,000	5700 or 5800	Telpak C	FDX	L
	500,000	5800	Telpak D	FDX	L

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