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ABSTRACT

This thesis describes the requirements for a buffer storage device, with respect to other system components and its own limitations, which is designed to aid in the economic transmission of processed data from a central computer to distant terminals. Proceeding from the fact that tariff rates on wide band educational television channels are attractive, but that the data format must be compatible with television images and must flow at a rate of 1200 bits per second (BPS), it deals with the major problem of converting sporadic bursts of computer output data into a serial rate of 1200 BPS through the utilization of a buffer storage device. An analytic study of input and output properties, a discussion of feasible assumptions, and descriptions of various models are presented, leading to suggestions for a suitable design of a buffer storage mechanism for the PLATO IV system. Actual data are employed in the determination of design alternatives. A brief outline of the PLATO system as it is currently conceived is also included. (Author/PB)

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DESIGN, STUDY AND SIMULATION OF SPACE-DIVIDED OUTPUT BUFFER FOR PLATO

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DESIGN, STUDY AND SIMULATION OF SPACE-DIVIDED OUTPUT BUFFER FOR PLATO

BY

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B.S., Rensselaer Polytechnic Institute, 1968

THESIS

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I wish to thank my advisor, Professor Donald E. Bitzer, for his guidance and encouragement in the formulation and evaluation of this project. I would also like to thank Robert E. Bohn for his patient handling of the Control Data Corporation 1604 during preparation and testing of this simulation.

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INTRODUCTION

Modern computers are capable of processing data at extremely high rates. However, to transmit this data economically to thousands of terminals located up to 150 miles from the central computer presents a major problem. The tariff rates on a wide band educational television channel open the possibility of economically transmitting data over long distances. The data format, however, must be compatible with television images so that regulations applying to these tariffs would not be violated. At the end of long transmission lines, the television channel must be able to branch into multiple telephone lines servicing the terminals. This communication system requires a peak and average rate of 1200 bits per second to be maintained, but the central computer generates bursts of output data for a student in microseconds. A buffer storage is necessary to hold the information while it is converted from the fast parallel output of the central computer to a serial rate of 1200 bits per second for each student.

The goal of this paper is to describe the requirements for this device with respect to the other system components and its own limitations. Leading up to suggestions for a suitable design, an analytic study of its input and output properties, a discussion of feasible assumptions, and descriptions of the various models studied will be presented. The objectives of this study and simulation is to use actual data to determine design alternatives for an output buffer to be used with the PLATO IV system. An outline of the PLATO IV system as it is currently conceived is also included.

THE PLATO SYSTEM

Project PLATO (Programmed Logic for Automatic Teaching Operation) is an experiment in computer-based education at the University of Illinois. It has evolved from a single terminal system to a computer classroom of twenty terminals using a high speed digital computer (Control Data Corporation 1604) as a central processor. Currently studies on the design of an economically viable large scale computer-based education system, PLATO IV, are under way. Establishing the computer as a flexible tool for developing cognitive skills is the purpose of this project. Presently material is available to the student in a great many fields written by authors who have chosen their teaching strategy from a variety ranging from drill and practice to student-directed inquiry.

Based on experience with the existing system, it appears economically and technologically feasible to develop a large scale system for handling 4000 teaching stations. The cost per student terminal-hour would be that of teaching at the elementary school level. The central computer will be required to process an average of 1000 student requests per second. It must be capable of transmitting at a peak rate of 4.8 million bits per second, and it must contain two million words of core memory.[1]

The present PLATO system uses a television screen with a keyset input as the individual student terminal. Replacing the television screen, PLATO IV will rely on the plasma panel (or similar device) now being developed. Because it can retain its own images (has its own memory), the plasma panel will reduce the load on, and therefore the cost of, the communication lines. Coupled with the plasma panel, at the terminals will be a slide selector and projector which allows prestored information to be projected on the transparent glass panel

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[1] D. Bitzer and D. Skaperdas, "The Design of an Economically Viable Large-Scale Computer-based Education System," Computer-based Education Research Laboratory Report No. X-5 (Illinois, 1969), p 12.

display.

Data arriving from the computer will enter the terminal through an input register. Peak data rates to the terminal will be held to 1200 bits per second because of the inherent limitations of the uncompensated telephone lines used at the terminating end of the network. This will enable twenty bit words to be transmitted at a rate of sixty words per second, an adequate rate for the applications envisaged. Since the central computer is capable of transmitting short rapid bursts of data, a buffer computer will be necessary to store this data and perform the parallel-to-serial data conversion for transmission along the communication lines. A block diagram of a proposed system illustrating the distribution system to several remote points is shown in figure 1.

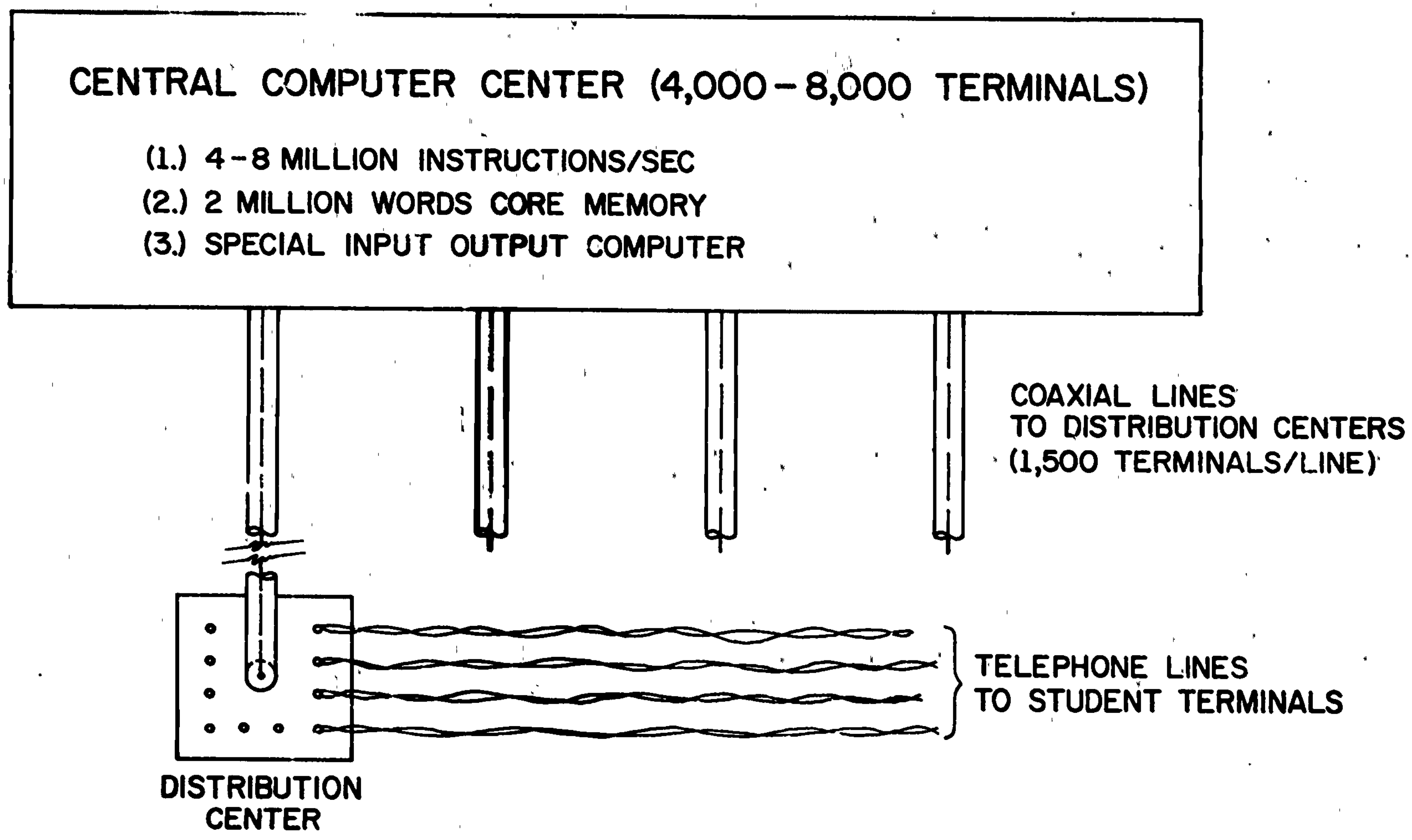

Figure 1. Distribution System for PLATO IV

SPECIAL PURPOSE BUFFER COMPUTER

To meet the requirements of PLATO IV as it is currently conceived, the output buffer computer must accept high speed input, store it, and transmit it on a 4.5 megahertz transmission line at 1200 bits per second for each student. This means that the output to the transmission line must consist of one bit for each student each 1/1200 second, or one word each [illegible] second, where each word usually contains one or more characters to be plotted on the student's screen. One way to accomplish this is to store the outgoing data in a main memory with the student identity retained as a tag, then shift the information into a smaller buffer containing one word per student and shift out one bit from each student each 1/1200 second. The access time from the main memory at approximately 800 microseconds would be much less than the time to shift out one bit. Consequently, data could be dumped into the smaller memory one word at a time as each word empties. See figure 2 for a schematic representation of the proposed configuration.

One of the main problems in the design of this device is the variation in rate of output from the central computer, especially in the number of words of data transmitted for each student. It has been shown from PLATO statistics that seventy (70) percent of all computer responses generate one character on the student's screen, each requiring one twenty bit word of output. Nevertheless, it is replies of more than one word that can tie up the available room in the output buffer, especially if they are very long (as many as 180 or more words) and if they occur close together.

For this reason, it has been decided to partition the main buffer into areas corresponding to output word length. Since one word for each student having data in the output buffer is emptied each 1/60 second, it is advantageous to provide room for as many different student requests as possible. Partitioning the output buffer will allow responses of few words to be shifted out rapidly

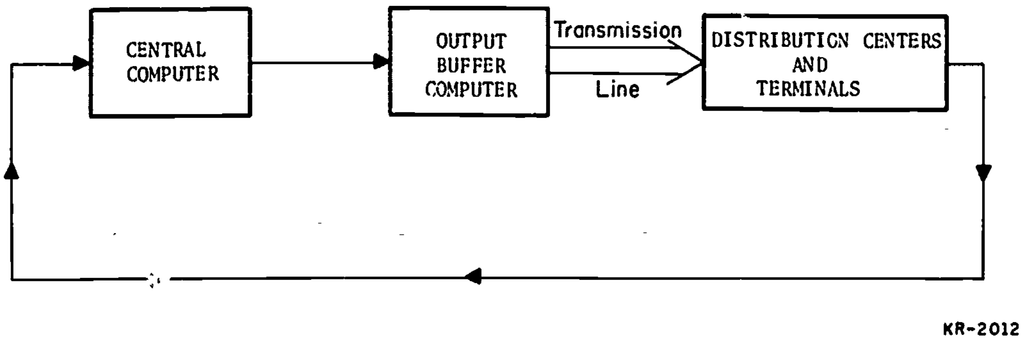

Figure 2a. Schematic of Computer System

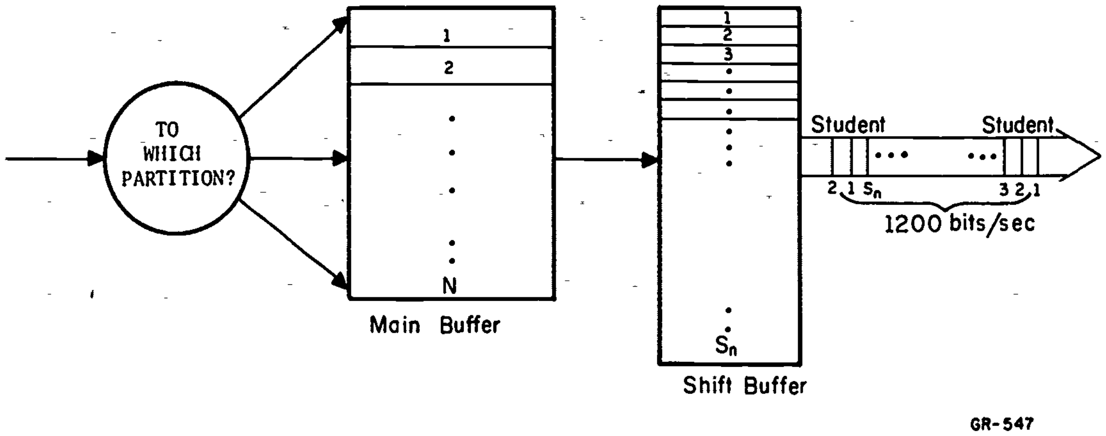

Figure 2b. Output Buffer Computer

allowing room for the next user, and responses of many words will be limited in the amount of memory they can occupy. The main task of this study and simulation is to determine the effect of dividing this memory so that it will be used efficiently, the data will not be lost for lack of room, and the cost factor will be small (the total number of words will be small).

STUDY

To investigate the flow of data into and out of the buffer computer, a model based on queueing theory can be used. First, assuming that the statistics are not a function of time, that is, that they are stationary, it can reasonably be assumed that inputs from 4000 terminals are Poisson distributed, that is, an input from any one is equally likely. Also, from PLATO statistics, it can be shown that the request rate probability density function versus execution time for student requests in the central computer is exponentially distributed, that is, as the execution time (holding time) increases, the number of requests decreases exponentially. In other words, the probability that service will occur in a time increment Δt is constant. It is independent of how long service has been in progress.[2]

From this discussion, considering the channel in the queueing theory to be the main buffer area in the output computer and the server to be the shift memory seems reasonable. This allows the waiting line to physically be located in the central computer or in the output computer. The queue disciplines considered are: first come - first served with requests for which there is insufficient room just waiting; or first come - first served with requests recycled which are not immediately able to enter the channel.

When formulating the equations necessary to describe the behavior of the system, it is apparent that the probability of the data being a particular length cannot directly be included in an analytical fashion. This information is available from PLATO statistical programs, but it cannot easily be incorporated into the difference equations governing the problem.

One way to define the input is to represent each category of length of

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[2] D. P. Cox and Walter L. Smith, Queues (London, 1961), p. 20.

request by its own weighted Poisson distribution where the weights would be determined by available figures:

$$p(k,t) = \frac{e^{-\lambda}\lambda^{k}}{k!} = \text{the probability of } k \text{ requests arriving in time } t \text{ where}$$

λ = the number of events in unit time. Letting $\lambda = mT_1$,

$$p(k,t) = \frac{e^{-mT_1}(mT_1)^k}{k!}$$

where m = the mean number of events in time T_1.[3]

By assuming that events of different numbers of words are independent, one can assign m_i as the mean number of events for each class of lengths. This leads directly to $p_1(k_1,t)$, $p_2(k_2,t)$, . . . $p_n(k_n,t)$ if there are n classes of length. Therefore,

$$\sum_{i=1}^{n} p_i(k_i,t) = \text{overall distribution, } p(k,t).$$

By assigning each class of length to a particular partition, the problem looks like a single channel case since a request in one queue can go only to a specific channel. One difficulty remains in the application of standard equations for a Poisson distributed input channel. Since the input has been defined in terms of the time and number of words in the request, no reference is made to the student terminal destination. It is this limited rate of one word every 1/60 second for each student that defines the service mechanism and it is not dependent on how much data has been transmitted or the time it joined the waiting line.

Assuming that at any instant of time, there is only one request per student in the main buffer simplifies the situation somewhat. However, at any time,

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[3] Harry H. Goode and Robert E. Machol, System Engineering (New York, 1957), p. 338.

there may be more than one request in any single division of the buffer and therefore more than one student represented. This indicates that the holding time of the system is not necessarily 1/60 second. The actual value of the holding time or the mean number of outputs from an occupied channel per unit time can be approximated by computing an average waiting time per user and multiplying by the total number of users. This average waiting time is based on the actual usage of the overall system and varies with the application in progress. Since the expected value of the holding time, $E(T_1)$, cannot be found analytically, the mean probability that the channel is busy, $p = mE(T_1)$, cannot be found.

Queueing theory helps establish criterion for the adequate functioning of the system. The channel and server system are considered unstable if the waiting line or queue become infinite in length. One way of expressing this is that the probability of any specified length of waiting time must tend toward zero as time increases.[4] Since these probabilities cannot be determined from the queueing relations, a numerical approach in which the criterion for instability is the existence of a waiting line which increases in time must be taken.

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[4] Ibid., p. 335.

NUMERICAL APPROXIMATIONS

Since the physical situation cannot be modeled by queueing theoretical relations, a numerical approximation was developed. The purpose of this analysis was to reach a first approximation for the size of the buffer partitions. In the process, it is necessary to assume a relationship between input and output which would be substantiated or refuted by the following simulation.

Statistics from the current PLATO system provide a great deal of useful information in deriving a numerical model. This data is obtained at the end of each classroom session and represents the usage of the current system. A plot of the percentage of keys pushed versus the number of characters plotted for each key is available. This describes the distribution of the lengths of the inputs to the space-divided output buffer. Also computed is the average usage of the system in number of seconds for each student request. Other information such as total number of keyset inputs and total time used are listed, but are not essential to this investigation.

Each category of number of characters plotted corresponds to one buffer partition as a first approximation. Also, each category can be represented by an average number of characters to simplify the calculations. A cursory glance at a sample plot shows that one category in particular is almost never used, that is the one with two characters plotted per key; therefore, for most of the original work this was included in the 3 - 10 character division. It is necessary to keep in mind the data format which will most likely be used on PLATO IV. Each twenty bit word will consist of one to three characters depending on the number of characters in the data. This means that one transmitted word can contain up to three six bit character codes plus a two bit identifier (identifying that these are character codes) packed up to three characters per word with the last containing any uneven multiple of three.

To determine a possible size for the partitions, it is first necessary to define the input and output rates in terms of the available information. The approximate number of output words transmitted with each keyset input can be found for each range of number of characters by:

$$\text{no. of words/key} = \frac{\text{\% keys pushed/category x ave. no. of characters/key}}{\text{no. of characters/word}}$$

$$= \text{\% keys pushed/category x ave. no. of words/key}$$

The approximate number of words per second for each student can then be calculated:

$$\text{no. of words/sec.} = \text{no. of words/key x ave. no. of keys/sec.}$$

Since the output rate could not be defined analytically, it is necessary to choose an expression for this rate and test this assumption against the response of the simulated system. The relationship chosen was:

$$\text{output rate} = K \text{ x input rate}$$

where K is an arbitrary constant of proportionality. By substituting different values for K, different approximations can be found for possible partition sizes. These values give a workable first guess for the buffer's divisions, and the accuracy of the assumption and the appropriate value of K which yields the best results can be checked against the simulation's response.

Letting N_i = the number of words reserved for category i and M = the number of students, it is possible to further specify the above equation:

$$N_i \text{ x } \frac{\text{60 words}}{\text{second/student}} \text{ x } \frac{1}{\text{ave. no. words/key}} = K \text{ x } M \text{ x } \frac{\text{number of words}}{\text{second/student}}$$

for each category i, assuming each keyset input corresponds to a different student. Table 1 illustrates the values of the parameters leading up to the evaluation of N_i for various values of K and with M equal to 1000 students. This

Table 1

Sample Values of Input Parameters and Corresponding N_i

(Average Per Station Rate = 1 Key Every 2.0 Seconds)

Parameter	1	2	3	4	5	6
Number of Characters	1	2-10	11-20	21-40	41-179	>180
Ave. No. of Words/Key	1	2	5	10	40	60
% Keys Pushed	0.60	0.02	0.02	0.06	0.07	0.01
Number of Words/Key	0.60	0.01	0.03	0.2	0.9	0.2
$\frac{\text{No. of Words}}{\text{Sec/Student}}$	0.30	0.005	0.015	0.1	0.45	0.1
* n_i	0.005	0.000167	0.00125	0.0167	0.30	0.1
† m_i (M = 1000)	5	.167	1.25	16.7	300	100
N_i (K = 1)	5	1	2	17	300	100
N_i (K = 2)	10	1	3	34	600	200
N_i (K = 5)	25	1	7	84	1500	500

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* $n_i = N_i/(K \times M)$

† $m_i = N_i/K$

is based on a fairly typical set of statistics for TUTOR logic programs. It is generally agreed that these programs generate longer responses to the terminals in shorter time periods than most other strategies of teaching or other modes of operation. Therefore, TUTOR statistics have been employed in this work, for the most part, to supply worst case loads on the output buffer. By designing this buffer for about 1000 students the transmission rate along the coaxial cable can be met and the central computer can attach four such devices to handle 4000 terminals.

Keeping in mind that the relationship involving K is only a guess, a range of values for the parameters discussed above can be found. These are presented in Table 2. These results are based on calculations similar to those in Table 1 for several different program applications mainly using the TUTOR strategy. Finally, by choosing K = 2, estimates can be made for possible partition sizes from the range of values shown in Table 2 and by rounding up by varying degrees. Table 3 lists some of the estimates.

Table 2

Range of Values of Input Parameters

Parameter	1	2	3	4	5	6	
Number of Characters	1	2-10	11-20	21-40	41-179	>180	
No. of Words Sec/Student	0.155	.025	0.023	0.03	0.27	0.1	
	0.33	.033	0.071	0.15	0.7	0.85	†
	0.515	0.05	0.11	0.35	1.4	1.5	
* m_i (M = 1000)	2	0.9	1.6	16	160	100	
	5	2	6	40	450	850	†
	10	9	9	55	1000	1500	
N_i (K = 2)	4	2	4	32	320	200	
	10	4	12	80	900	1700	
	20	18	18	110	2000	3000	

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† ——— = approximate average of data considered

* $m_i = N_i/K$

Table 3

Possible Partition Sizes
(K = 2)

	1	2	3	4	5	6	TOTAL
Number of Characters	1	2-10	11-20	21-40	41-179	>180	
Minimum Partitions	4	2	4	32	320	200	562
To Hold Max Words in Category	4	4	7	32	320	200	567
Average Partitions	10	4	12	80	900	1700	2706
Largest Calculated	20	18	18	150	2000	3000	5206
Largest + 5%	21	19	19	158	2100	3150	5467
Rounding Up	25	20	20	160	2500	3500	6325

SIMULATION

Since the overall behavior of the output buffer cannot be described analytically, it is necessary to simulate the system by a computer program. The actual program was written in FORTRAN for the Control Data Corporation 1604 computer. The assumptions made during the study phase are used as the basis for the simulation, also. However, these must be translated into numerical quantities first and tied together by an all-encompassing mechanism.

Without going into detail about the inner workings of the program, it is important to understand the overall scheme. Although the program does not operate in real time, simulation time is the key factor. By filling a word in the buffer with the time it will be empty, this value can be compared against that of a master clock which will indicate whether there is room for new data. In this way, it is also possible to determine (1) if a student has a current response in the buffer, (2) if sufficient time for the student to generate a new request has elapsed, or (3) if he is still waiting for data for which there is no room in the output buffer.

The three dimensions of this problem are the time of occurrence of an event, the student for whom it is intended, and the number of characters (or words) in the data. It is assumed that the holding time of the input to the space-divided output buffer is exponentially distributed. Therefore, an event is equally likely to occur in any given time increment Δt. By choosing Δt it is possible to limit the number of events which occur in a longer period of time. This philosophy was used to generate the master clock mentioned above. The average time for each keyset input per student station available from PLATO statistics is divided by the assumed number of students, 1000. This yields the average time between requests for the total system. Dividing this in half approximates the exponential relationship, where the number of divisions equals two, and this is the time Δt during which events are equally likely (the clock step time). Numbers between 0.0 and 1.0 are pseudo-randomly generated by the computer. These numbers are used to determine whether or not an event occurs during Δt depending on which side of one-half the number falls. In this fashion, over a long enough period of time, the desired input rate is very nearly reproduced. In addition, the random number generator can be used to identify the student terminal destination.

Choosing the number of words in each request was by far the most complex manipulation. The percent of keys pushed versus the number of characters plotted information is used to weight the probability that an event is in a particular category. The random number generator is also used to determine in which character space the request would belong by summing these distributional fractions. Once the range of the number of characters is determined, a uniform distribution is assumed to exist within each category. That is, the exact number of characters is computed by converting a randomly generated decimal into a number within the limits of the division already chosen. This number of characters can then be divided into some number of words by using the prescribed data format. This procedure not only specifies the number of words in the request, but also performs the decision function of which space-division the data will enter and if necessary which of the waiting lines it will join.

MODELS

Several models of the space-divided buffer were studied with each model more closely approaching a realistic operating system. In most of the simulations, memory was considered to be static. That is, whenever a word of data enters the buffer it stays in a particular location until it is shifted out. These programs also require that all the data in any request be placed in consecutive words of memory, therefore, before a new request can enter a buffer partition, one sufficiently large empty space must exist in that division. Since words are shifted out one every 1/60 second for each request, spaces may exist, but they may be too small for the incoming data in that category, so there may not be room for the new request.

The original program discarded data for which there was no room in the buffer division for which it was intended. This is a crude approximation to the queue discipline in which data is forced to wait until space is available. It roughly assumes that the waiting line is located outside the space-divided computer and that the next time an event occurs for the division previously filled, it is the same information that has already been rejected. Because of the random nature of selection of the parameters describing a given event, the new information does not precisely duplicate the old discarded data. Also, these recent events should not be included in the calculated average rate as they are in this model. However, the number of events for which room is not available does provide a reasonable measure of the capacity of the system.

Since the output rate is based on the presence of only one request for each student at any given time, if a second request is generated for a particular student while the first is still present anywhere in the main memory, this data is also discarded. It is possible for a second event to be generated in the simulation before a student would physically be able to enter a new request into the central computer and for the computer to transmit data in response. Also, it is doubtful that a student would push a second key before he received the response to his previous key. Therefore, a more realistic treatment was developed.

In the PLATO distribution statistics used, there is a category in which a keyset input requires no response from the central computer. One possible source of these inputs is the space bar which simply marks the next available position on the television screen (or plasma panel). Another possibility is that the student pushed an erroneous key, one which was not recognized and therefore elicited no response from the current system. It is felt by those involved in the implementation of PLATO IV that such inputs would receive some one word response indicating that the student should try again from an acceptable key. For this reason, the second version of the simulation adds those events previously requiring no action to those requiring one word responses. The simplest way to affect this is to place these events in the category of one character (one word) requests. Since space bar inputs will still require no response from the central computer, this is a worst case approximation.

A system delay time of one-tenth second is required between consecutive requests from the same student. This key-pushing time limitation was incorporated into the third simulation. It still seemed possible for a student to enter a new request before the stored output from his previous request was completely transmitted, so the fourth model eliminates the student identification altogether and assumes that each request is from a different station. This seems to be a reasonable assumption unless over 1000 requests are being serviced at any instant of time.

However, to insure that only one request per student is actually present in the output buffer, a retry scheme was inserted in the grogram. In the fifth model the student's identity is retained and if he tries to generate a new request either before the one-tenth second keying time has elapsed or if data is still being transmitted to him from the main memory, the choice of this student as the originator of the incoming information is declared erroneous and a new student identity is sought. This approach would insure that the student waits for the response to one keyset input before making another. This model seems to fit the physical situation most closely and has been employed in all future simulation programs.

These five programs are related by their method of discarding data for which there is no room in its intended buffer division. In the sixth model a waiting line is employed to retain this information and retry it until there is space available or it has spent a maximum allowable time in the queue. Retry is attempted just as or directly after data is shifted out of the main memory (every 1/60 second). In this way, those requests which have been in line the longest have the first opportunity to be placed in the buffer. Also, all data in the waiting line is eligible for storage in the buffer before the next event is generated. Especially for categories with a broad range of possible numbers of words, the shorter bursts of data would probably be stored before longer ones, since free areas only open up one word at a time. Therefore, it is conceivable that the first entries in the waiting line will not be served until the shorter ones behind them have been transmitted. For this reason, a maximum time of one second is allowed for any piece of data to remain in the waiting line without being serviced. This same time limit is set for the main memory to be entirely full.

If data is rejected because it has waited too long, the system would fail (shut down) in order to retry it. This is highly undesirable, so such failures must be kept to a minimum (hopefully zero). It is very likely that the waiting line will fill faster than the buffer can empty, therefore, a totally full memory implies that the queue length is at least finite or more likely increasing in size so that the system is becoming unstable.

The next four modifications are concerned with saving memory by merging one or more of the previously defined categories. Model seven merges categories one and two so that the first division represents data of 1 - 10 characters. Model eight merges categories two and three so the second partition contains responses of 2 - 20 characters. Divisions one, two, and three are combined in model nine so that 1 - 20 character responses are in one partition. Similarly, model ten combines the first four partitions so data of 1 - 40 characters is in one category.

To compare the buffer requirements of the partitioned system to that of one mass of memory, another program was written which allowed data of any length to fill in any consecutive free words of memory. Also, a variation of model ten was developed in which words of memory are shifted to fill in free areas as they become available. Because of the time consumed in the shifting process, conclusive results could not be obtained.

RESULTS

Many hours of computer time have been employed to obtain meaningful results from these simulations. The distributional data used is considered to be fairly typical of the current system. The actual numbers used are composites of lessons that performed similar functions at similar average rates. For instance, lessons with many requests each second usually require proportionally more short responses than ones with many characters. Scanning statistics from quite a few different sessions revealed distributional patterns which the statistics tested represent.

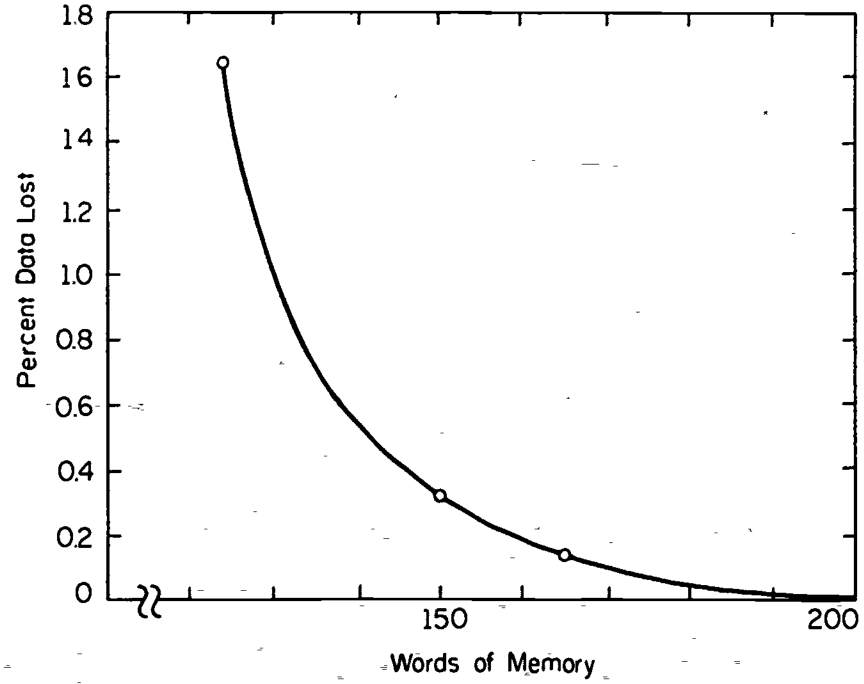
Questions have arisen as to the accuracy of some of the data from the current system for testing the performance of PLATO IV. In the new system many of the requests now generating long strings of plotted characters will instead call for prestored slides. Thus, it is likely that the division representing the longest responses (greater than 180 characters) will not be referred to as often as it is now. The actual usage is difficult to estimate, but authors are currently the main users of this last category, and the percent of their usage will decrease as the number of terminals increases. Therefore, the percent of keys pushed in this last partition was limited to three percent of the total keyset inputs.

By observing the response of the simulated system to distributions of different type lessons, an overall memory allocation was derived. Each set of statistics was chosen to weight a different partition (or partitions) of the main memory, since the response of each division is independent of the others. At any given PLATO session, these weighted partitions are accessed more frequently than others, but all divisions will not be filled to maximum capacity. Therefore, allocating memory to handle the peaks in several distributions will yield a worst case design.

Remembering that parameters are randomly selected, that is, that no simulation is identically reproducible, comparisons of the various simulation programs can be made. For a first guess as to buffer assignments, no significant difference was noted between versions one and two. This indicates that at least for this number of words (50) in category one, the added number of one word replies adds no substantial load to the first partition. For this reason, and because no other differences in the responses of the simulated systems are noticeable, this worst case approximation was retained in future work.

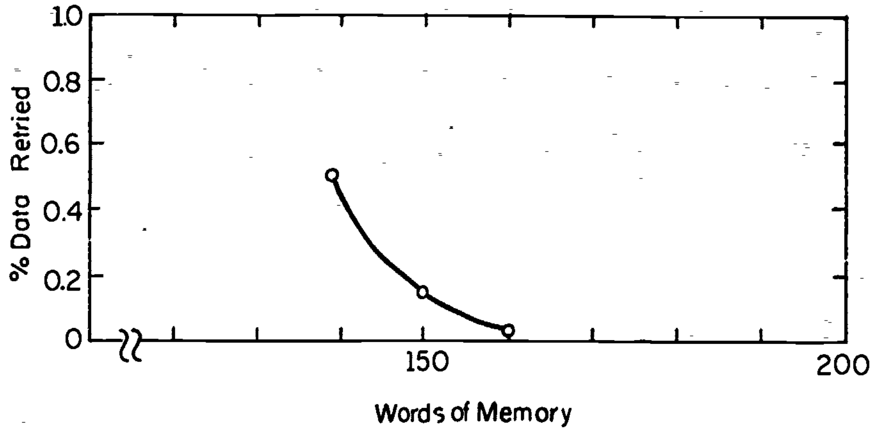
Adding the one-tenth second keying time between consecutive requests from the same student caused the percent of data rejected because of closely spaced student requests to drop about one percent. The space-divisions showed no marked change in activity. Disregarding the student identity in version four increased the load on all partitions and thereby increased the percent of data rejected because of insufficient space. This increase is particularly apparent in the categories corresponding to longer strings of data (the last two). This is indicative of a trend which is more noticeable in the programs that follow. As the load on a partition increases, that is, as the number of requests increase or the allowable words of memory decrease, the percent of data for which there is no room increases proportionally faster than the load. See figure 3 for a graph illustrating this phenomenon.

In version five, which employed the student identity retry technique, it never happened that all students had a request in the buffer at the same time. This points out that there are never more than 1000 requests in the output buffer at any time. The responses of the space-divisions did indicate a decrease in load over that of version four, and the percent of data rejected was approximately that of version three (without retry for student



[For category 4 (21-40 characters) using model 5 and distribution 0.60,0.02,0.02,0.07,0.06,0.01 at 2.0 seconds/keyset input]

Figure 3a. Percentage of Data "Lost" Versus Words of Memory Allocated



[For category 4 (21-40 characters) using model 6 and same distribution as above]

Figure 3b. Percentage of Data Retried Versus Words of Memory Allocated destination). Since this method yields results comparable to previous work, insures that one request per student is present in the main memory at any time, and requires each student to wait for the response to one request before initiating another, this approach was maintained in the following programs.

In most cases the data retry technique produces about equal percentages of retries as the percentage of requests lost in version five of the simulation. In the partitions handling longer strings of characters, retrying data seems to add interference and somewhat more requests are retried than those rejected in the previous version. If there is insufficient room available in the output buffer, data can spend some time in the waiting line without decreasing turn-around time by a great deal. For this reason, fewer words of memory may be required to handle the same load on the space-divided buffer as when data is simply rejected. These requests in the queue constitute interference to data which seeks room in the main memory for the first time. Therefore, studies were made to determine how much room is necessary in the space-divisions with this retry scheme. As mentioned above, decreasing the number of words available increases the number of retries. Therefore, one percent of the requests in that category was set as the maximum number of retries in each division. This leads to a buffer allocation of:

characters/category	words of buffer needed
1	25
2 - 10	15
11 - 20	40
21 - 40	160
41 - 179	1600
greater than 180	2000
TOTAL	3840 words

By combining some of the smaller divisions, the shorter bursts of data are able to fill the available words between larger bursts. This phenomena leads to savings in the number of words required. It is significant to note that the first four categories constitute less than one-tenth the total number of words required, so this merging process may not save much buffer space. Table 4 lists suitable buffer allocations based on the various merges investigated. These results reflect the one percent limit on the number of retries in each partition.

Describing the output buffer by one mass of memory instead of a group of partitions creates no retries and actually uses about 1000 fewer words of memory than the total necessary for the space-divided system. This would allow considerable savings in the memory assignment at the possible expense of protection to the user of the smaller categories. This savings occurs because otherwise empty areas are filled by short requests. One attempt was made to compare the effects of shifting the words in each partition to fill empty words as they develop. However, the shifting process is so time consuming that too much computer time would be necessary to obtain meaningful results. This time problem is one that may exist in the physical system also.

Table 4

Suggested Buffer Allocation for Less Than Six Partitions

Total Words	1 - 10	11 - 20	21 - 40	41 - 179	>180
3830	30	40	160	1600	2000
	1	2 - 20	21 - 40	41 - 179	>180
3825	25	40	160	1600	2000
	1 - 20	21 - 40	41 - 179	>180	
3815	45	160	1600	2000	
	1 - 40	41 - 179	>180		
3780	170	1600	2000		

DISCUSSION

Before discussing the significance of the above results, it is important to compare them to the assumptions made. Scanning the print-out of the number of requests made by each student, it is apparent that they are within a few percent of each other. This bears out the assumption that even with the student retry scheme, the terminal destination is Poisson distributed. For the buffer assignments chosen, a maximum of about 100 requests can exist in the main memory at any time. Therefore, the presence of at most one request per student at any instant is likely. The average request rate on the current system is one keyset input every 4.0 seconds. A distribution based on this average rate shows no retries for the buffer allocation chosen. Therefore, the statistics used and the design derived are certainly worst cases for PLATO III.

Comparing the final set of partition sizes to the suggested sizes indicated by the above numerical approximations reveals that the relationship,

output rate = 2 x input rate

is a close estimate of the actual behavior of the simulated system. The larger divisions represent the average sizes calculated while the smaller ones are closer to the rounded-up suggestions. It is possible that for a particular distribution some other proportionality constant would be more applicable. However, for the overall system, K = 2 fits fairly well.

In applying the above partition allotment to PLATO IV, some of the possible differences between the two systems should be considered. As mentioned above, the load on the smallest partition may be increased on PLATO IV over that of the current system. However, the simulations overestimated this usage, so the actual significance of space bar inputs should be determined on the new system. The question of author usage will have to be answered after the new system is in operation. How often the longest strings of characters are generated and how they will be handled by the system are problems faced by PLATO IV. Since more terminals will be available, varied types of teaching strategies may be used at the same time. Therefore, the overall distribution of keyset inputs may be flatter than those of current statistics. This would lead to fewer peak loads and thereby fewer words of memory in the space-divided output buffer. Also, once users adjust to the system they may input to the central computer in bursts to receive the fastest response. This type of input would alter the usage distribution again.

It is somewhat disquieting that the unpartitioned system requires less memory than the divided buffer. This occurs because small bursts of data are able to fill in the groups of free words which develop between large requests. Also, each distribution tested does not use the total capacity of all partitions since the overall allotment is based on the responses of several different distributions. Therefore, requests which would otherwise have been retried find space in the areas not used by other partitions as well as between requests. These seeming advantages must be balanced against the possibility that a few large requests might enter the output buffer within a short time span and almost completely tie up the entire buffer. In this case, the expense of those few extra words would protect the small requests from being blocked out of the buffer.

There are several compromises to this dilemma. The most straightforward approach would be to maintain at least a few partitions and shift the words to fill in free areas. This could also be accomplished by not requiring that data in a particular request be placed in consecutive locations. Either

As the results show, merging a few categories saves some buffer space and produces few additional retries. This concept could be extended to the two largest categories. By allowing data of over 41 characters to enter one partition, the otherwise empty areas in the largest division would be at least partially filled. Also, since no situation has arisen in which both categories have been filled to capacity, a savings of several hundred words might be affected. With this approach, the short requests are still promised sufficient room. Other combinations of merged categories are also possible, but the total number of words involved is small compared to the number used in the last two partitions. A system with at least two partitions and at most five using this last combination might provide the most practical output buffer.

The partition sizes suggested by the results of these simulations indicate an upper limit of about 4000 twenty bit words of buffering required to satisfactorily receive data from the central computer and shift it onto a transmission line. There are still several alternative approaches to the design of the output buffer which should be studied. Total size and effectiveness as well as facility of implementation should be considered before a final choice is made. Once PLATO IV is in operation, some of the above questions will be answered and these designs can be tested.

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13. ABSTRACT

Modern computers are capable of processing data at extremely high rates. However, to transmit this data economically to thousands of terminals located up to

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Khinchine, Aleksander Y., Mathematical Methods in Theory of Queuing, translated from the Russian by D. M. Andrews and M. H. Quenville, New York: Hafner Publishing Company, 1960, (No. 7 of Griffin's Statistical Monographs and Courses).

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Computer-assisted Instruction						
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PLATO						
PLATO IV						
data transmission						

APPENDIX A

FLOW DIAGRAM FOR ORIGINAL PROGRAM

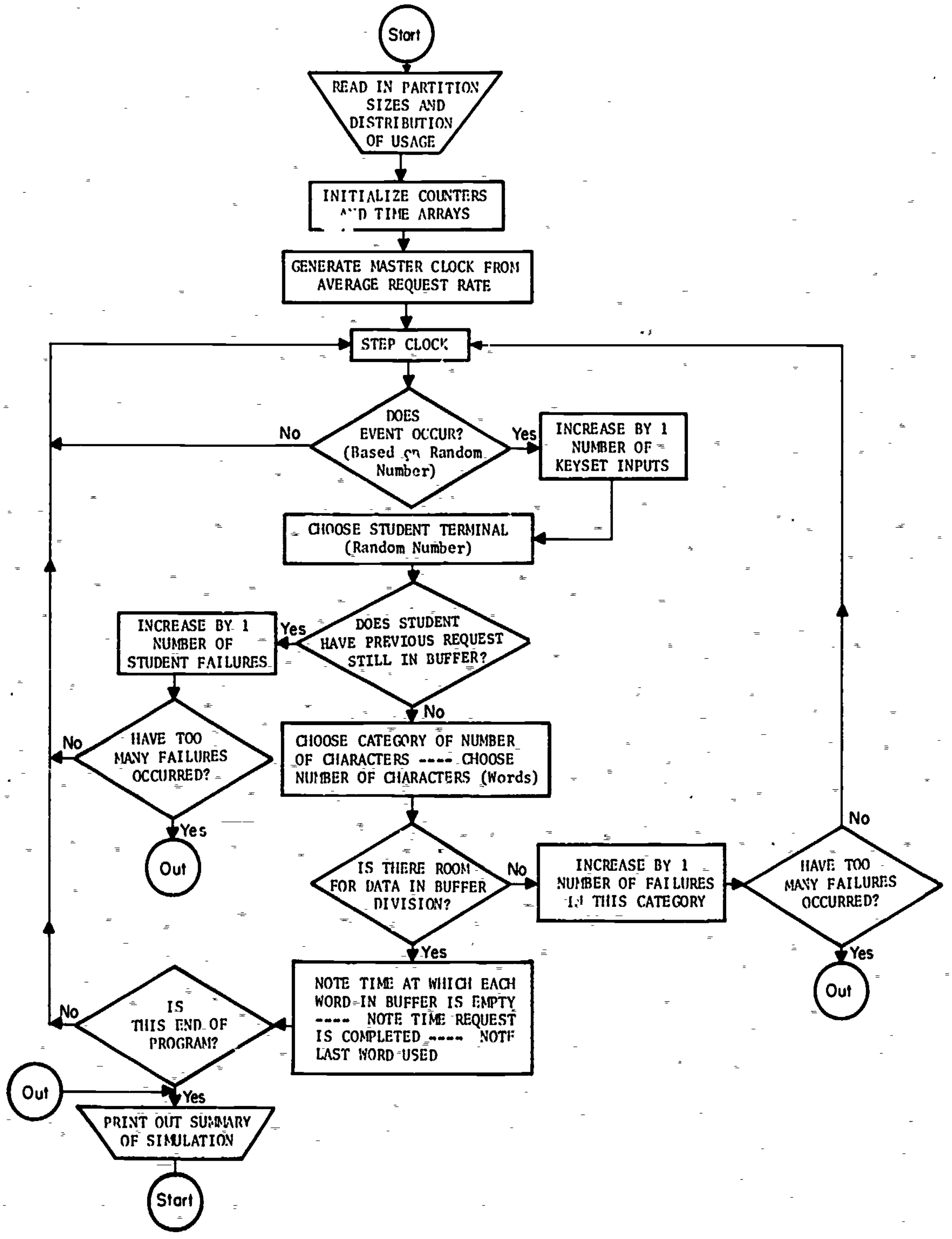

Figure 4. Flow Diagram for Original Program
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APPENDIX B

FLOW DIAGRAM FOR MODEL OF SIMULATION WITH DATA RETRY

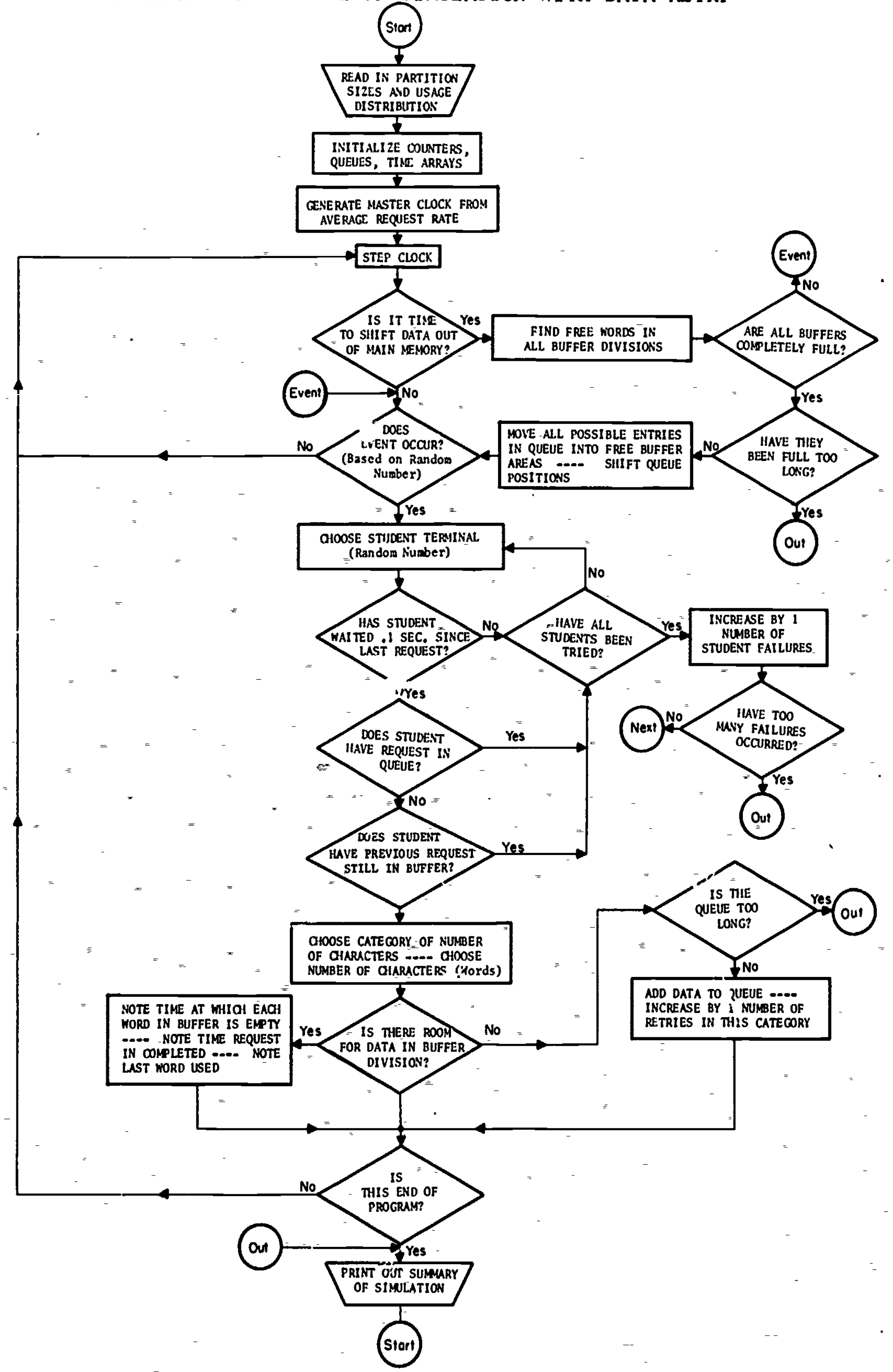

Figure 5. Flow Diagram for Model 6 of Simulation with Data Retried

APPENDIX C

SUMMARY OF DATA

TABLE 5

Percentage Data "Lost" for Various Distributions
Buffer Partitions: 50, 20, 50, 200, 1500, 2000 Words

		MODEL 1		MODEL 2		MODEL 3		MODEL 4	MODEL 5	
		Original		+ 1 Word Replies		+ 0.1 Sec Keying		Each Student Different	Student Retry	
		*Buf.	†Stu.	Buf.	Stu.	Buf.	Stu.	Buffer	Buf.	Stu.
1 Key / 2.0 Sec	.60	0	3.2%	0	3%	0	2.1%	0	0	0
	.02	0		0		0		0	0	
	.02	0		0		0		0	0	
	.07	0		0		0		0	0	
	.06	0		0		0		0	0	
	.01	0		0		0		0	0	
1 Key / 2.5 Sec	.55	0	4.35%	0	5%	0	3.9%	0	0	0
	.06	.01%		0		0		0	0	
	.05	.01%		.02%		0		.02%	0	
	.11	.02%		.016%		0		.045%	.046%	
	.13	1.7%		.51%		.57%		3.3%	.97%	
	.03	0		.03%		0		.39%	.01%	
1 Key / 1.5 Sec	.70	0	4%	0	4%	0	2.77%	0	0	0
	.05	.01%		.017%		.008%		.01%	0	
	.03	0		.015%		.058%		.03%	0	
	.05	0		0		0		0	0	
	.04	0		0		0		0	0	
	.02	.03%		.26%		.1%		.63%	.057%	
1 Key / 4.0 Sec	.65	0	1.65%	0	1.6%	0	.7%	0	0	0
	.07	.04%		.03%		.005%		.005%	.013%	
	.02	0		0		0		0	0	
	.04	0		0		0		0	0	
	.04	0		0		0		0	0	
	0	0		0		0		0	0	
1 Key / 2.2 Sec	.62	0	5%	0	5.15%	0	4.25%	0	0	0
	.03	0		0		0		0	0	
	.02	0		0		0		0	0	
	.09	.01%		0		0		0	.01%	
	.10	.18%		.08%		.12%		1.25%	.07%	
	.04	3.2%		3.9%		3.7%		10.5%	4.5%	

TABLE 5 (Cont'd)

		MODEL 1		MODEL 2		MODEL 3		MODEL 4	MODEL 5	
		Original		+ 1 Word Replies		+ 0.1 Sec Keying		Each Student Different Buffer	Student Retry	
		*Buf.	†Stu.	Buf.	Stu.	Buf.	Stu.		Buf.	Stu.
1 Key 1.8 Sec	.72	0	4.3%	0	4.37%	0	3.56%	0	0	0
	.03	0		0		0		0	0	
	.03	0		0		0		0	0	
	.03	0		0		0		0	0	
	.06	0		0		0		.05%	0	
	.03	1.3%		1.17%		1.5%		5.8%	1.27%	
1 Key 2.8 Sec	.52	0	4.4%	0	4.5%	0	3.56%	0	0	0
	.04	0		0		0		0	0	
	.01	0		0		0		0	0	
	.10	.008%		0		0		0	0	
	.11	.008%		.019%		.008%		.23%	.016%	
	.04	.33%		.7%		.89%		3.3%	.72%	
1 Key 3.2 Sec	.75	0	2.6%	0	2.5%	0	1.73%	0	0	0
	.05	0		0		0		.014%	.006%	
	.04	.005%		0		0		0	0	
	.02	0		0		0		0	0	
	.03	0		0		0		0	0	
	.03	0		.043%		.014%		.071%	0	

---

* Percentage data "lost" due to insufficient buffer space.

† Percentage data "lost" due to closely spaced student requests.

TABLE 6

Percentage Data "Lost" for Various Buffer Allocations
Percentage Keys Pushed/Category: 0.60, 0.02, 0.02, 0.07, 0.06, 0.01
at 1 Keyset Input/2.0 Seconds

BUFFER ALLOCATION	MODEL 1		MODEL 2		MODEL 3		MODEL 4	MODEL 5	
	*Buf.	†Stu.	Buf.	Stu.	Buf.	Stu.	Buffer	Buf.	Stu.
50	0	3.2%	0	3%	0	2.1%	0	0	0
20	0		0		0		0	0	
50	0		0		0		0	0	
200	0		0		0		0	0	
1500	0		0		0		0	0	
2000	0		0		0		0	0	
45	0	3.1%	0	3.3%	0	2.3%	0	0	0
15	.02%		0		0		0	0	
45	0		0		0		0	0	
175	.018%		.027%		.015%		.028%	.004%	
1400	0		0		0		.024%	0	
1900	0		0		0		0	0	
40	0	3%	0	3.3%	0	2.2%	0	0	0
10	.42%		.42%		.21%		.42%	.55%	
40	0		.023%		.071%		0	0	
150	.16%		.18%		.13%		.22%	.21%	
1200	.015%		.025%		.052%		.19%	.016%	
1800	0		0		0		0	0	
30	0	3.1%	.021%	3.5%	.008%	2.2%	.17%	.21%	0
15	0		.021%		0		0	0	
30	.28%		.19%		.33%		.4%	.35%	
125	1.4%		1.34%		1.15%		2.42%	1.53%	
1000	.67%		.39%		.53%		2.1%	.62%	
1500	0				0		0	0	

TABLE 7

Percentage Data Retried for Six Partition Buffer

		BUFFER ALLOCATIONS		
		30, 15, 30, 140, 1200, 1800	25, 10, 35, 150, 1400, 1900	20, 15, 40, 160, 1500, 1900
1 Key 2.0 Sec	.60	0	.002%	.16%
	.02	0	.14%	0
	.02	.089%	0	0
	.07	.53%	.167%	.28%
	.06	.097%	0	0
	.01	0	0	0
1 Key 2.5 Sec	.55	0	0	0
	.06	.063%	2.37%	0
	.05	2.7%	1.2%	.36%
	.11	3.3%	1.25%	.57%
	.13	15.0%	4.6%	1.8%
	.03	.62%	.21%	0
1 Key 1.5 Sec	.70	0	.31%	4.37%
	.05	.31%	5.4%	.37%
	.03	3.1%	.68%	.26%
	.05	.06%	0	.04%
	.04	0	0	0
	.02	.84%	.23%	0
1 Key 4.0 Sec	.65	0	0	0
	.07	0	.57%	0
	.02	0	0	0
	.04	0	0	0
	.04	0	0	0
	0	0	0	0
1 Key 2.8 Sec	.52	0	0	
	.04	0	.87%	
	.01	0	0	
	.10	.9%	.4%	
	.11	1.1%	0	
	.04	3.9%	1.8%	

TABLE 8

Percentage Data Retried for Five Partition Buffer

1	2	3	4	5
1 - 10	11 - 20	21 - 40	41 - 179	>180

Buffer Allocation	0.61, 0.05, 0.11, 0.13, 0.03 1 Key/2.5 Sec	0.75, 0.03, 0.05, 0.04, 0.02 1 Key/1.5 Sec
35	0	.025%
40	.37%	.17%
160	.98%	0
1500	1.5%	0
2000	0	.4%
30		.39%
40		.32%
160		0
1500		0
2000		.39%
25		5.75%
40		.19%
160		0
1500		0
2000		0

1	2	3	4	5
1	2 - 20	21 - 40	41 - 179	>180

20	0	16%
45	.175%	.024%
160	.73%	.125%
1500	1.3%	0
2000	.255%	.1%
25	0	.28%
40	.23%	.17%
160	.65%	0
1600	.52%	0
2000	.14%	0

TABLE 9

Percentage Data Retried for Four and Three Partition Buffer

1	2	3	5
1 - 20	21 - 40	41 - 179	>180

Buffer Allocation	0.78, 0.05, 0.04, 0.02 1 Key/1.5 Sec
65	.002%
160	0
1500	0
2000	0
55	.025%
160	0
1500	0
2000	0
45	.48%
160	0
1600	0
2000	.12%

1	2	3
1 - 40	41 - 179	>180

	0.77, 0.13, 0.03 1 Key/2.5 Sec
200	.01%
1500	1.5%
2000	0
170	.105%
1600	.72%
2000	0

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