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EVALUATING TIME-SHARED COMPUTER USAGE*

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[illegible]

The development of time-shared computer systems 1/ has led to major technical and philosophic changes within the computer field during this decade.2/ Computer manufacturers have available both computer hardware and software systems specially designed for time-sharing usage. The Advanced Research Projects Agency (ARPA) of the Pentagon has given increasing amounts of support to M.I.T. and other academic (and non-profit) communities for research into time-sharing. The Joint Computer Conferences sponsored by AFIPS 3/ has devoted an increasing number of sessions at their meetings to time-sharing.

The primary concern voiced in these meetings and the published literature appears to center around problems of the design and development of the time-shared computer system -- little or no interest seems to have been generated for an evaluation of these systems as to their usefulness for present or future users.

The need for such a formal investigation into the usefulness of time-sharing is highlighted by: (1) the lack of information concerning the value of the characteristics of time-sharing computer systems which makes these systems differ from the more traditional batch-processing computer systems; and (2) uncertainty as to the usefulness of time-sharing systems or the premium (if any) that must be paid for this service.4/ This proposed research will evaluate time-shared computer system usage by means of a

rr investigation into the relationship between user
rf , behavior, and attitudes and the characteristics
  b the time-shared computer systems and the comparable
c nventional computer systems.

Introduction

R. M. Fano has stated, "The notion of machine-aided cognition implies an intimate collaboration between a human user and a computer in a real-time dialogue on the solution of a problem, in which the two parties contribute their best capabilities. . . ". (16) Others with considerable experience in this area have also added their support to the development of interactive time-shared computer systems to aid in this man-machine collaboration. 5/ Indeed, from a reading of the published literature concerning both machine-aided cognition and time-sharing, one gets the impression that there is almost unanimous agreement that the use of such systems for this 'intimate collaboration between a human user and a computer' produces far more productive, efficient, and effective results than could be obtained with any other type of system. Those persons responsible for major developments in the field of time-shared systems believe that they will, among other things:

> improve the ability to program. . .open up several new forms of computer usage 6/

> increase productivity of 'computer catalyzed research' that results from close man-machine interface. . . 7/

Unfortunately, no systematic studies are available to support the above statements. There appears to be an emotional commitment to these systems rather than a formal investigation of existing conditions. Most of the people in the field have apparently relegated formal investigation to a low priority level. In fact, the first published

re rence to this problem (and one which did not appear u almost four years after work began in the field) questioned whether:

> The promoter-scientists of time-sharing are systematically, scientifically, and economically exploring it; <u>or whether time-sharing is good or bad and f hat purposes</u>. All they seem to be concer with is, which kind to design, build, or bu 8/ (underlining added)

In addition, at the October 1965 meeting of the Los Angeles ACM chapter three advocates of time-sharing conceded the absence of any comparative evaluation of time-shared systems and batch-processing systems 9/.

Some of those persons developing time-shared computer systems have attacked proposals for formal investigation into the value of time-sharing as both unwarranted and incorrect. They advance the following reasons for their attitude: first, time-shared systems are so newly developed that the users do not yet know how to make use of these systems; second, present time-shared systems are experimental in nature and should not be advanced as representative of such systems of the future; and third, it is alleged that time-sharing applications are qualitatively different than batch-processing applications and therefore cannot be compared with them.

There is no doubt that these statements are substantially correct -- time-shared systems are new, developing, and different than the more traditional batch-processing systems. However, it is not necessarily true that the stated conclusions follow from the facts. At

this point, it must suffice to point out that although some time-sharing applications will have qualitative differences when compared with batch-processing applications, the majority of the applications are expected to be compatible with both types of systems. In addition, there are people who know how to use these systems, and who have enough knowledge of the characteristics of future applications, to design an investigation incorporating at least some of them. These aspects will be discussed in detail below.

r . of Evaluating Interactive System Usage

The interactive time-shared systems are described as 'faster', 'more efficient', and 'more productive'. 10/ These terms, as used, are both ambiguous and not amenable to measurement unless made more precise. For example, 'faster' could refer to the total elapsed t from the start of a problem to its completion, but it ld also refer to the total amount of the man's time, th otal amount of the computer's time, or even the computer's response time. The problem is that the potential evaluator can have no notion of which meaning of 'faster' is relevant to the persons using the term.

As another example of this problem, a prel nary investigation of one measure of 'efficiency' f that the use of an interactive time-sharing system for p cing a working FORTRAN program resulted in a six-fold increase in computer time used 11/ (When compared with the time required for the same problem done on a non-interactive computer system). However, this is acceptable as 'evidence of the inefficiency' of interactive time-sharing usage only if there is agreement between the relevant evaluators that the above is the one valid measure of 'efficiency'.

Another problem that appears here concerns the determination of whom the relevant evaluators are. It is doubtful that any group formed solely of programmers, users, or people paying for the computer system would be acceptable as evaluators to those persons to whom an evaluation might

be addressed. -- mixed groups would doubtless find it difficult to agree on acceptable measures.

The methodological differences between computer applications using interactive time-shared systems and the more traditional computer systems result in further problems. For example, the programming of a problem on these two types of systems can be expected to result in a different allocation of time for problem definition, program writing, statement declaration, debugging, editing, compiling, analysis, waste time, think time, reacquaintance time, and total time to complete the problem.

In addition, an evaluation could be further complicated by attempting to compare the two systems by using a problem which is not fully defined on the traditional system. This could result from an application which uses features of an interactive time-shared system as an integral feature of the task. For example, a task in which the user and the computer would converse frequently with each other fits into this category because it depends greatly on the rapid response available with a time-shared system. Although this type of work could be done on a traditional batch-processing system, the large amount of interaction required makes it impractical.

An integral factor in this lack of formal investigation is probably prompted by the (usually found) electrical engineering and computer science background and orientation of those persons responsible for the design and development

of the interactive time-shared systems. Few, if any, have had a behavioral science orientation or the training necessary for designing and conducting formal investigation to evaluate man-machine interactive aspects of the usage of these systems.

It would thus appear that both the commitment to the time-sharing concept and the lack of a behavioral science orientation of the designers and developers of such systems are the primary factors responsible for this lack of scientific investigation into the supposed advantages of interactive time-sharing.

Scope and Purpose

The above suggests four possible sets of variables relevant to an investigation of this area, namely those which: (1) are characteristic of the computer systems under study; (2) concern the attitudes of the users of these systems; (3) are measures of the user's behavior and usage of the computer system; and (4) are measures of the results (output) produced by the man-computer system.

Figure 2

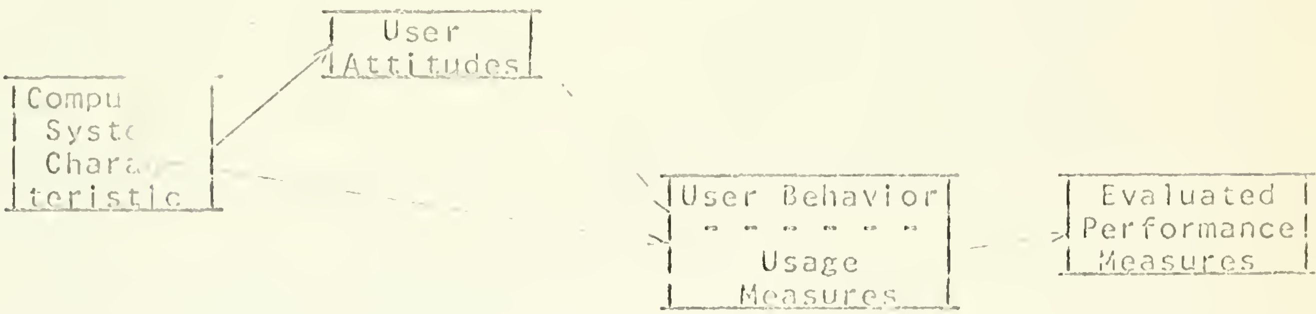

Figure 2 displays the conjectured relationships between these four sets of variables. More specifically, preliminary experimentation and the viewed literature provides support for the following major conjecture:

> As a result of the characteristics of a time-shared computer system, the user of such a system will have more favorable attitudes toward both the use of this computer system and the results he produces while using it than he would if using a traditional computer system. Both the characteristics and the ensuing more favorable user attitude will result in the user producing results faster and more efficiently than he could if using the traditional computer system. Finally, the results produced by the user exhibit a quantitatively higher performance level than the results produced if a traditional computer system had been used.

Before discussing each of the above sets of variables in detail, it should be noted that the conjecture specifically refrains from stating that either computer system will be proven 'better' than the other -- this could be attempted only if 'better' was interpreted by each and every user in exactly the same way. However, each user assigns different values and trade-offs to his requirements for speed of solution, cost, access speed, and system size for each type of application. The scope of this study will be limited to investigating the usage of both time-shared and the more traditional computer systems and providing a means of evaluating the use of either type of system (or some combination of each) over a range of applications.

Computer System Characteristics

The major independent variables to be considered in this research are those which represent the differences between interactive time-shared computer systems and the more traditional computer systems. These variables can be conveniently categorized as those which result from (1) differing feedback delays; and (2) differing degrees of interaction between the user and the computer system. In addition, it is alleged that proper use can be made of these characteristics of interactive time-shared systems to produce qualitatively different response to the user.

The elapsed time the user must wait from submission of his program to the return of results is a measure of the

feedback delay. Interactive time-sharing systems would be expected to have normal feedback delays measurable in seconds while the traditional systems would measure this in hours or days. The degree of interaction between the user and the computer can be measured by both the delay involved before a request for service is recognized and the difficulties a user encounters in making one extra computer run. Although admittedly a gross measure, we shall consider a computer system as interactive if the response to a normal input is expected rapidly enough that the user does not turn to other work while waiting for the response to his input. 12/ The rapid interaction between the user and the computer available only with a large time-shared computer allows the implementation of a programming system in which the user can take an active part in the computing-problem solving process -- the man-machine symbiosis so often discussed.

User Attitudes

As a result of these differences in the characteristics of the computer systems under investigation, it is expected that a user's attitude toward both the computer system used and the results produced while using this system will differ. In particular, it is expected the rapid feedback feature of the time-sharing system will increase a user's evaluation of the usefulness of both the computer system used and the results of any given interaction with the computer system. In addition, the ability to immediately correct errors and re-run a program available with

time-sharing should result in a smaller change in a user's level of satisfaction after an unsuccessful computer run than if the user had used a traditional computer system. For the same reason, it is expected that a time-sharing user's estimate of progress toward completion of the project would be less affected by an unsuccessful run than would the estimate of a user of a traditional computer system.

> (1) The user of a time-sharing system will rate the usefulness of both the computer system and the results of a computer run higher than will the user of a traditional system.
>
> (2) The negative influence of an unsuccessful computer run on a user will be stronger in a batch-processing than a time-sharing environment.

<u>User Behavior and Usage Performance Measures</u>

When evaluating <u>usage</u> of a man-computer system, we are concerned with both the amount of elapsed time required to obtain a solution to a problem and the efficiency with which this solution could be obtained.<u>13</u>/ Experience with both time-sharing and the more traditional computer usage leads us to expect the faster feedback available with a time-sharing system will result in a problem solution requiring a shorter elapsed time for completion.

The man-computer systems under study will also be evaluated by measuring both components of the cost efficiency and the methods of usage of the two systems. The cost efficiency is determined by calculating the cost of both the man's time and the computer's processing time for each system. We would expect that usage of a time-sharing

system will result in a lower cost of the man's time and a higher cost of the computer's time. The <u>cost efficiency</u> will depend upon the balance between the savings resulting from a reduced number of man-hours and both the increased number of hours of computer processing time consumed and the higher cost of time-sharing usage.

The method of usage is a measure of the degree to which the user relegated programmable problem solving to the computer system. As a result of the user's attitude concerning the accessibility and useability of time-sharing, we would expect the user to relegate a larger number and percentage of the programmable tasks, such as checking for errors, to the computer while concentrating his attention on non-programmable tasks, such as analysis of logical errors and decision-making. This does not really mean that such usage is more or less efficient than usage of a different computer system. Rather it indicates differential modes of behavior while using these systems -- behavior which may influence the final results produced.

<u>Conjectures</u>: (1) The use of a time-sharing computer system will result in a task solution sooner than the solution could be obtained with a batch-processing computer system.

(2) The use of a time-sharing computer system will result in a greater amount of computer processing (and higher computer processing cost) than corresponding usage of a batch-processing computer system. However, this usage of a time-sharing computer system will require fewer man-hours than for a corresponding batch-processing computer system.

(3) The differential user attitudes toward the two types of computer systems will result in greater use of the time-shared system -- however, this greater use will result, in part, from a greater reliance, by the user, on the computer for routine tasks.

External Evaluation of Performance

The purpose of the external evaluation of performance is to make available a measure of the output of the man-computer system which is arrived at independently of the user's methods or the computer system used. To accomplish this objective both the results produced by the user on the computer system and an evaluation (by a competent evaluator) of the user's understanding of the problem and implementation of a solution will be used to judge performance.

The published literature suggests that time-sharing usage will: "improve the ability to program"; "open up several new forms of computer usage"; and "increase (the) productivity of 'computer catalyzed research...". From preliminary experimentation it appears that, in fact, the use of time-sharing _does_ allow the user to produce 'better results' -- if the task in question is to analyze a problem and produce a decision-rule, the user of the time-sharing system will produce a better decision rule. If the task is to produce a working computer program, the user will produce a program in which results are more often correct, have done more checking of inconsistencies in the data, or is more completely documented than a program produced by a user of a batch-processing computer system.

Conjecture: The results produced by the user of the time-sharing system will exhibit a higher level of performance than the user of a traditional computer system.

Experimental Design

Introduction

The selection of an appropriate research setting, experimental task, and experimental subjects is important in every investigation of this type. Since one purpose of thhs research is to provide answers to questions concerning the value of time-sharing usage, the research settings and tasks selected should have relevance for both 'real-world' programmers and managers in terms of their potential uses of time-sharing systems. In addition, the experimentation must be conducted with subjects who are competent users of these types of computer systems.

Three research settings at M.I.T. were selected as appropriate in terms of the above criteria: (1) a graduate course in Industrial Dynamics, given by the Sloan School of Management; (2) an advanced undergraduate programming course, given by the Electrical Engineering Department; and (3) an introduction course in management information systems also given by the Sloan School of Management. The first and second courses require the students to program, debug, and analyze problems using the MIT Computation Center's IBM 7094 computer which is used for both time-sharing and batch-processing applications. The third course makes use of the Sloan School's non-time shared IBM 1620 computer for the same type of work.

The Industrial Dynamics course was included in this study because Industrial Dynamics requires the use of a

system for the primary purpose of analyzing the characteristics of computer simulation models and designing management policies based on their analysis. The undergraduate programming course was included to investigate the behavior of experienced programmers working on a fairly well defined problem which primarily required programming effort. The management information systems course was included because it would allow an investigation of the effect of providing a 'better' quality and different amounts of computer response to the user while maintaining the same feedback delay -- a feature not found in the other two settings.

Experimental Tasks

The task to be used in the Industrial Dynamics course assignment will involve the analysis of market dynamics in a 'Construction Industry'. Each student in the course will be required to take the role of a small-scale independent builder within this industry who is trying to maximize his average profits in light of certain market dynamics. Through his analysis of the market and its behavior, the student is expected to arrive at a decision rule for starting apartment construction that will accomplish this goal.

The task for the Industrial Dynamics course will be administered through the use of a 'case' assigned as a homework problem. The actual problem will be both simple and highly constrained, with the construction of the

Independent builder's decision rule to maximize average profits: the primary area for creative work. The students will be required to complete the programming of a simulation model of this 'case' (using the DYNAMO programming language 14/), debug the program, analyze the results, and propose and test a decision rule to be used by the independent builder.

The assignment for the advanced programming course will be the programming of a theorem proving algorithm in the field of mathematical logic using the MAD-SLIP programming system available on the IBM 7094.

The management information systems course will require the programming of an accounting and inventory control assignment for a manufacturing company. The student will be assigned to one of the two FORTRAN-compatible programming languages available on the non-time shared IBM 1620 computer and will be allowed to program the problem in any way desired.

The students' primary concern in the three assignments will be with the course project required by the instructor -- the data collection questionnaires will be explained as an outside research project having no influence upon their grade for the assignment. As a result, the students should be primarily motivated by the class assignment -- a stronger motivation to participate than that provided by most laboratory experiments which use a small sum of money as the primary motivator.

Methodology

The general methodology for all three experimental tasks will be described in two distinct phases: (1) the procedure for conducting the research; and (2) the data to be collected and the method of collecting it. In addition, a description of the Industrial Dynamics pilot study will be discussed.

Experimental Procedure

The experimental tasks will be presented to the students as part of the normally required course assignment for all three courses. While assigning the problem, the instructor will notify the class that a research group (in the case of the Industrial Dynamics course, the Industrial Dynamics Research Group) is involved in a study of some aspects of computer usage and will be collecting data concerning the methods used by the students in completing assignments of the type being assigned to the class. Before the assignment is presented to the students, they will be asked to fill out pre-experimental questionnaires (see the next section for a discussion of the data to be collected through the use of this questionnaire). Based on their answers, students with similar backgrounds will be paired and each assigned to a different experimental treatment -- this assignment will be done on a random basis.

Each student's assignment to either the time-sharing or batch-processing computer systems (or, in the case of the management information systems course, either of the two

FORTRAN compatible programming systems) will be handed out along with the course project material. During the assignment, and before the students begin using the computer, they will have several questionnaires to complete. In addition, after each use of the computer, the students will be required to complete a short questionnaires pertaining to that interaction with the computer.

The students using the batch-processing system will be able to submit their computer runs once or twice each day -- depending on the course they are in. The students assigned to the time-shared system will be able to use the computer at almost any hour of the day or evening. For the Industrial Dynamics course, the students will have four consoles available for their exclusive use -- all four consoles will be continuously 'logged in' to the time-shared system and the students will have access limited only by the other students using the consoles for the same purpose.15/ For the advanced programming course, the students will be able to 'log in' to the computer from a console anywhere on the M.I.T. campus. In the case of the management information systems course, time on the Sloan School's IBM 1620 computer will have been reserved for several periods during the day in addition to normally scheduled service runs.

Data Collection

The data will be collected by both the questionnaires completed by the students during the assignment and/or of

th computer input and output of each student. This will be done to: (1) discover how each student works; and (2) cross check the data obtained from the quesionnaires the students completed.

These questionnaires will take several forms: First a pre-experimental questionnaire to gather background information before any manipulations take place. Second, a questionnaire administered before the students make use of the computer will investigate the influence of knowing that they will be using one or another computer system. Third, a questionnaire completed after their analysis of each computer run to investigate the students' attitudes and behavior during the course of the experiment and to obtain measures of progress, time expended, and the type of work done. The fourth type of questionnaire, administered after the students have completed the assignment, will investigate the above factors on a overall basis as well as requesting comments concerning the assignment. The final questionnaires will be administered three weeks after the experiment and will measure the degree of interaction between the students while solving this problem.

The data to be collected through questionnaire and/or content analysis of the printed output will be: (1) the amount of time expended on the experimental task and the distribution of that time over the period the expe[illegible]nt is in progress; (2) the categorization of this expend[illegible]e into analyzing results, making changes, waiting for [illegible]rn

of results, etc.; (3) the number of computer runs submitted; (4) analysis of types of changes made and the reasons for these changes; (5) analysis of types of errors; (6) student's evaluation of the 'usefulness' of each run's results; and (7) student's evaluation of 'effectiveness' of each run's results.

Pilot Study

One pilot study has been conducted to investigate the use of the particular Industrial Dynamics task (the 'case' study of the Construction Industry), and the use of the data collection devices. For the pilot experiment, several students who had previously taken the Industral Dynamics cours[illegible], were asked to participate in a pre-test of the experi[illegible]t. After completing the experimental task they were asked for individual comments concerning the presentation of the experiment, the interest generated by the task, and the data collection devices used. All pre-test subjects were requested to refrain from discussing the experiment with anyone -- it appears as if this request was honored.

Som Pos ible Experimental Difficulties

The following are several potential problems inherent in the design of the proposed research: First, the appropriateness of both the experimental settings and the experimental tasks could be questioned -- especially by those who believe that time-sharing applications have not yet been developed and, when they have been developed, will be qualitatively different than traditional applications. This assumes that the area of time-sharing and batch-processing applications do not and will not overlap. In fact, experience to data on several operating systems has shown many areas where this overlap is substantial. 17/

The possibility of communication from one subject to a future subject is a potential problem in the conduct of the experimental tasks. Whether the content of the communication had value or not, the conduct or actions of the other subjects in the experimental situation might be affected in some way. Although emphasizing the importance of independent work to the students may not insure they work ir ndently of one another, measures taken after the s' ts receive their grades will allow for control of this p: em.

The last important area of potential problems concerns data collection and the filling out of the 'Data Sheet' by the subjects participating in the first task after each computer run. There may be some problems connected with requiring the subjects to remember the necessary dat

However, the only alternative to the proposed method of data collection is the use of a time record, divided into ten or fifteen minute intervals, which the subjects would fill out during each interval. The 'Data Sheet' method was chosen to eliminate the possibility of subject antagonism resulting from the large amount of time required and both intentional and unintentional errors and biases introduced as a result of using the second method.

Summary and Implications

To briefly summarize the major hypotheses of this research, it has been predicted that the user of a time-sharing computer system will demonstrate a higher level of performance than will the user of a more traditional computer system. Further, it was predicted that this higher level of performance will result from differential usage of the two types of computer systems and that the characteristics of each computer system affects the user's attitudes toward the computer system.

The major potential implication of this study is that persons responsible for the design and selection of computer and information systems should consider the trade-offs among their requirements for speed of solution, cost, access speed, and size of the accessible system before determining the type of computer system to be used.

In addition, it is hoped that this study will provide a basis for evaluating time-sharing and/or interactive computer systems which have been designed to: (1) provide an immediate 'debugging' tool for the programmer; (2) provide the researcher with the ability to test conjectures hunches at the time they occur; (3) provide the teacher with a tool for immediate response to student inquiries; and (4) provide a system to the manager for the purpose of experimenting with several different policies in a simulated environment so the policy exhibiting the desired characteristics can be implemented.

It is important to realize that an organization's requirements for a computer or information system may be such that implementation of a timesharing system would not only increase the total cost of a computer system, but also downgrade the service previously provided with a traditional computer system.

FOOTNOTES

1 Two definitions of time-sharing by experts in the field are: "By a time-sharing computer system I shall mean one that interacts with many simultaneous users through a number of remote consoles. Such a system will look to each user like a large private computer". McCarthy(32). Also, "By time-sharing we mean those systems in which the facilities of a computer complex are rapidly commutated among independent users who are each on-line at a remote console." Glaser and Corbató (20). The terms 'interactive' and 'time-shared' will be used interchangeably in the following discussion. It should be realized, that although time-shared computer systems are interactive, the reverse is not necessarily true. We are considering, in this discussion, computer systems which are both interactive and time-shared.

2 See McCarthy (32), Corbató (6), Fano (16), and Licklider (27) for a discussion of the changes that have resulted from this development.

3 The American Federation of Information Processing Societies is composed of three primary groups; the Association for Computing Machinery, the IEEE, and the American Documentation Institute.

4 The additional "out of pocket" expense required for time-sharing results from the extra computer hardware and software required, the time-sharing accounting, the transmission lines and user consoles, and the system maintainance. However, since the method of usage of these systems is presently unknown, any costs or savings resulting from this usage cannot be calculated.

5 See Licklider (27), Corbató (6), Schwartz (40), and Stotz (45).

6 Corbató, Daggett, and Daley(7).

7 Dennis (11).

8 Fein (18), p. 14.

9 (9), p. 103.

10 When asked to compare interactive time-shared systems with batch-processing computer systems, both part-time and professional programmers were almost unanimous in their agreement that interactive time-shared systems are 'better'. When pressed to define 'better', they say first that they are able to do a 'better' job on such

systems, thus increasing their satisfaction. They also point out that the time to complete this job is less than it would have been had they used a batch-processing system. These programmers do not explicitly cite other measures of productivity, efficiency, or effectiveness. (These observations resulted from informal contacts with professional time-sharing programmers at M.I.T. and Systems Development Corporation.)

11 When the end products (the working programs) were evaluated, there was no apparent difference in the final programs produced. There was, however, a difference in the total elapsed time to produce these programs. There seem to be two components causing this increase; first, the use of the Project MAC time-sharing system required twice as much processor time for printing and editing programs as for compiling them -- a three-fold increase in processor usage; and second, the behavior of the users apparently changed as a result of the greater availability of the computer with time-shared systems. This resulted in a greater number of compilations (and the accompanying increase in printing and editing) than would have occurred with the traditional batch-processing system -- this increase have been variously estimated with estimates ranging betw n 50% and 400%.

12 It should be noted that thi efinition is relevant only in terms of on-line system traditional batch-processing systems a y their very nature and design, non-interactive.

13 We are making the simplifyi assumption that the solution could, in fact, be obtained. We could, if necessary, treat this as another variable.

14 The DYNAMO programming language is described in Pugh (37) and Forrester (17). Industrial Dynamics is described in Forrester (17).

15 Preliminary experimentation indicates this number of available consoles to be sufficient to handle the students' requirements of access.

16 We are assuming that these students have the same qualifications as those students who will participate in the actual experiment -- with the exception of having completed a ful course in Industrial Dynamics.

17 We are referring to the experiences of two experimental time-sharing systems Project MAC at M.I.T. and TSS at System Development Corporation, and two commercial time-sharing systems, the IBM QUIKTRAN system and the KeyData system.

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