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A METHODOLOGY FOR EVALUATING
TIME-SHARED COMPUTER SYSTEM USAGE

by

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ABSTRACT

The development of time-shared computer systems has led to major technical and philosophical changes in the computer field in this decade. A large number of designers, manufacturers, and users of such systems have expended great amounts of effort in the development of the capabilities of the computer and the means to use it. However, little or no effort has yet been expended to evaluate these systems in terms of their usefulness for present or future customers.

The research reported here has focused on the development of a methodology through which time-shared computer system usage can be evaluated. It is based on a study of the characteristics and design of present and proposed computer systems, as well as relevant behavioral theory and research. Five categories of variables are included in the resulting methodology, namely those which are measures of: (1) the cost of using the system; (2) the performance produced through the use of the computer system; (3) the speed with which results could be produced; (4) the amount of learning resulting from the use of the computer system; and (5) the attitudes of the users of the computer system.

The methodology developed was tested experimentally through evaluating usage of two computer systems, each exhibiting certain characteristics of both time-sharing and batch-processing. The primary problem under study was the effect of rapid feedback and unlimited computer access in a problem-solving situation -- the secondary investigation involved the effect of qualitatively different feedback upon computer programming.

The testing of the methodology indicated that the following are important parameters in an evaluation: (1) the nature of the application; (2) the interaction between the relative accessibility of the computer system studied and the length of time available for the user to perform the required task; and (3) the monetary value assigned to both the man's and the computer system's time.

As a result of the two evaluations attempted, there appears to be sufficient evidence for concluding that time-shared computer usage can be evaluated and that the methodology presented may be both sufficiently effective and general to be used for evaluation of time-sharing usage over a wide range of applications. However, no attempt should be made to generalize the results of these specific evaluations to all time-sharing systems or applications.

The testing of the methodology yielded unexpected findings related to the effect of continuous sessions with the time-shared computer system. Measurement of the changes in user performance indicated that the first effective interaction of a session with the time-shared computer resulted in a greater amount of problem-solving than subsequent interactions during that session -- a result in conflict with current literature. The report concludes with a discussion of the implications for the role of feedback delays in a man-machine system.

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CHAPTER I

Introduction

The concept of time-sharing computer systems¹ was publicly advanced first in 1959 as a method for utilizing computer system time previously wasted through the necessary use of slow mechanical components as part of an electronic system (Strackey, 1959). In the many years which followed this pioneering work, the time-sharing concept was expanded so that "the motivation for time-shared computer usage (arose) out of the slow man-computer interaction rate (then) presently possible with the bigger, more advanced computers." (Teager and McCarthy, 1959). By 1960, the concept of time-sharing had expanded to include the view that the user and the computer could and should work together to achieve more effective results than could be achieved by either working alone. (Licklider, 1960).²

1 Two definitions of time-sharing by leaders 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, 1962) 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, 1964)

2 In general, this research is not limited to computer systems which, technically, are time-shared. The term 'time-sharing' has been used in this work primarily because of its popularity -- it should be recognized that this term will be used to refer to any on-line computer system which interacts with the user.

At Massachusetts Institute of Technology in late 1961 it was shown that time-sharing could be implemented -- at least on an experimental basis. (Crisman, 1965). Work then proceeded on implementation of a full-scale time-sharing system which was operational within two years. Since that time, the Advanced Research Projects Agency of the Department of Defense (ARPA) has supported much of the development of time-shared computer systems in many academic and non-profit organizations, although their "interest is basically in the improvement of interaction between man and computers, not time-sharing per se." (Licklider, 1965).

In view of the high level of effort being allocated to the design and implementation of time-sharing systems, it is somewhat surprising that little investigation has been initiated to study either the effect of time-sharing on man-computer interaction or the value of time-sharing itself.³ Little or no interest seems to have been generated for an evaluation of these systems in terms of their usefulness to people.⁴ In fact, the first published ref-

3 Work in progress at the System Development Corporation under ARPA support is attempting to investigate several aspects of computer programming under both time-sharing and batch-processing operations.

4 In the general computer field the large amount of attention devoted to time-sharing in computer publications and at computer conferences appears to concentrate almost exclusively on problems of the design and development of the time-shared computer systems.

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

The promoter-scientists of time-sharing are systematically, scientifically, and economically exploring it; or whether time-sharing is good or bad and for what purposes. All they seem to be concerned with is, which kind to design, build, or buy. (Fein, 1965)

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 (Datamation, 1965).

Can Time-Sharing Usage Be Evaluated?

Before any attempt can be made to evaluate time-sharing usage, two prerequisites must be met: (1) a methodology with which to evaluate such usage; and (2) an application, or usage, to be evaluated. The first of these consists of a well defined set of measures which, when applied, will result in an evaluation of time-sharing usage. The second is a time-sharing application suitable for evaluation. The problems involved in defining this methodology and providing acceptable conditions for testing and evaluation are discussed below.

The lack of a methodology for evaluating time-sharing usage does not appear to be due to an absence of statements concerning the 'value' of time-sharing. The leaders in this field have stated that usage of these systems will:

(1) "increase productivity of 'computer catalyzed research' " (Corbató, Daggett, and Daley, 1962); (2) decrease the time needed to solve a problem; (3) "open up several new forms of computer usage" (Corbató, 1964); and (4) allow the computer and the human user to interact in some 'more optimal' manner than is presently possible on non-time shared computer systems. These pronouncements appear to provide some base for defining measures of time-sharing usage and, ultimately, an evaluation function in terms of these measures. This methodology would use these statements to develop global categories of usage, such as speed, efficiency, and productivity which would later be further defined as operational measures.

The second task -- selection of applications with which to test this methodology -- requires study of both the current state of time-sharing and the future direction of time-sharing applications and computer systems. This 'current state' must be known, at least to the point of determining if any time-sharing applications are available to test the methodology -- while knowledge of the 'future direction' is necessary if the available application selected is to have some relevance to future time-sharing applications.

A survey of available time-sharing installations identifies a number of facilities which are sufficiently well designed and diverse in their capabilities to permit rea-

sonably sophisticated man-machine interaction.⁵ Although at the present time a large proportion of these installations' capacity is dedicated to extend the capabilities of these systems further, a significant amount has been made available to users for whom time-sharing is a new tool -- a tool with the potential of increasing their capabilities to produce meaningful work; for the scientist this might take the form of a programming language with immediate computer feedback; for the architect, this might result in a system that allows him to design a building using a display screen and light pen and immediately visualize the effect of his changes; for the social scientist, it might well result in a system that allows him to simulate a social environment of interest, make changes in this simulated environment, immediately scan the effect of these changes, and introduce the most promising conditions back into the real environment.

It seems unreasonable to assume that the multifarious experience using time-sharing over the past several years has not shown and affect the future direction of time-sharing. It would appear that this experience has not only

5 For example, the Compatible Time-Sharing System (CTSS) at MIT and Project MAC allows the user to program in twenty-five different computer languages; solve civil engineering geometric problems; manipulate strings, lists, and symbols; simulate; use CRT displays and light pens for a specially designed on-line programming system; search and retrieve bibliographic data from scientific journals; use the computer as an algebraic desk calculator; create manuscripts; and manipulate the users' files.

provided input to determine those applications and services whose design are not acceptable, but also those which are acceptable. Since future changes in these applications will probably reflect more of a change in emphasis than a change in basic direction, it is unreasonable to restrict the development of methods for evaluating time-sharing computer usage.

Research Undertaken

The research reported here is focused on the development of a methodology for evaluating time-shared and alternative computer system usage.⁶ It is based on a study of the characteristics and design of present and proposed computer systems as well as relevant behavioral theory and research. The primary relationships investigated are those involving performance, user behavior and attitudes, and system usage.

The methodology developed was tested by investigating its use in two experimental settings. Using the primary experimental task, the effect of rapid feedback and unlimited computer access in a problem-solving situation was studied -- using the other task, the effect of qualitatively

⁶ It would appear that this assumes an application which is fully defined for both computer systems. In practice, if an application cannot be completed using a given system, performance is lacking and the computer system is, by definition, unacceptable for that application.

different feedback upon computer programming was investigated.⁷

No attempt was made to respond to the question, "Are time-sharing computer systems better than [some other type of] computer system?"⁸ -- it should be quite apparent that such a question would be impossible to answer for all possible cases because: (1) the result of an evaluation of one application using one computer system cannot legitimately be generalized to all applications on all computer systems; (2) the cost to time-share a computer system fluctuates as these systems develop -- even the cost of different time-sharing systems can differ greatly; and (3) the appropriate comparison may not be between the use of time-sharing and another type of computer system, but between the use of time-sharing computer systems and some non-computer alternative -- including neglecting the task.

The second chapter presents a discussion of the theories and research relevant to the understanding and development of measures of time-sharing usage. Chapter III presents a model of time-sharing usage as well as a methodology for evaluating time-shared computer usage. The experimental design, setting, tasks, data gathering procedures,

7 Both of these studies were necessarily conducted on a limited sample of actual users in a somewhat restricted environment.

8 Most often this 'other type of computer system' referred to is a batch-processing system, but there is no reason it cannot refer to a different type of on-line computer system.

and hypotheses used to experimentally test the methodology are described in Chapter IV. Chapter V contains the report of the statistical analyses. The sixth chapter discusses the testing of the methodology and suggests possible extensions of this work. This chapter also contains a discussion of the implications of the research findings for the design of man-machine interactive systems.

CHAPTER II

Theory and Research

since John McCarthy's 1961 lecture "Time-Shared Computer Systems, (McCarthy, 1962) attempts to justify time-sharing have almost always led to a discussion of machine-aided cognition. For example, in describing the value of Project MAC¹ (and time-shared computer systems in general), Fano 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. In order for this intimate collaboration to be possible, a computer system is needed that can serve simultaneously a large number of people and that is easily accessible to them, both physically and intellectually. (Fano, 1965)

The "best capabilities" of both man and the computer were more fully spelled out by Licklider:

The great value of computers lies (sic) in their ability to execute very rapidly and very accurately procedures that have been defined explicitly and in detail. . . (i.e.,) algorithms.

Bright humans shine in the setting of goals, the generation of hypotheses, the selection of criteria -- the problem-solving phases in which one has to lay down the guide lines, choose approaches, follow intuition, exercise judgment or make an evaluation. These aspects are called heuristic. . . (Licklider, 1965)

¹ Project MAC (for either [or both] Machine Aided Cognition or Multiple Access Computer) is an MIT research project designed to provide a research tool and community for the study of interaction between man and machine. It is generally agreed that Project MAC is in the forefront of the time-sharing field.

Licklider further pointed out that the reason for developing time-sharing was to increase the possible man-computer interaction:

In the general run of computer applications today, the heuristic aspects of problem solving are almost wholly separated from the algorithmic aspects. The heuristic contributions are made by human problem-solvers, before their programs get into a computer. Then the heuristic contributions cease abruptly, and the execution of algorithms begins. (ibid.)

He apparently believes that the primary value of time-sharing lies not in the direct services it supplies the user, such as immediate access and very fast response time, but in the ability of the user to both introduce the computational power of a computer early in the problem-solving process -- to aid in the evaluation of alternative solution methods -- and to insure that computer results and problem formulation are meaningful in terms of the total problem and are not an end in themselves.

Others with considerable experience in one or both of these fields have also added their support to the development of time-shared computer systems to aid in this man-machine collaboration.² After viewing the literature in this area, a reader would reasonably believe that there was almost unanimous agreement that the user of such systems for this 'intimate collaboration between a human user and a computer' produces far more productive, efficient,

2 See Corbató (1964), Schwartz (1964), and Stotz (1963).

and effective results than could be obtained with any other type of computer system. The following comments describing the expected results of time-sharing usage are typical:

improve the ability to program. . .open up several new forms of computer usage (Corbató, Daggett, and Daley, 1962)

increase productivity of 'computer catalyzed research' that results from close man-machine interface. . . (Dennis, 1964)

Results of a Survey of Time-Sharing Users

Before discussing either the empirical research in the area of time-sharing or the theory and research in other related areas, it would perhaps be instructive to present the results of a summer's interviewing of seventy-five users of Project MAC at MIT. (Neisser, 1964) Although Neisser described his interviewing methodology as informal, his report serves as the best available systematic source of descriptive information to date concerning users of a time-sharing system. His work concentrated on obtaining the opinions of time-sharing users concerning several important areas: speed with which results could be obtained; usage of computer time; and the users' estimates of the effect of time-sharing upon the work in which they were then engaged.

Neisser's users reported that the elapsed time they required to obtain a solution to a given problem was substantially less with the use of a time-shared computer

than it would have been with a comparable batch-processing system. Their estimates of the savings in elapsed times ranged from a factor of one hundred times faster for simple programs to a factor of two for extremely complex problems.³ These estimates cannot, of course, be treated as 'statistical proof.'

Most respondents felt they 'wasted' computer time -- partly as a result of remaining at the console beyond that point where they were producing 'efficient' results. The users continued to "beat their head on a logical wall" well beyond the time they logically would have interrupted their session with the computer.

It appears that this direct and rapid interaction with the computer encouraged less attention to simple errors easily caught by the computer. The users did not bother to spend as much time checking their programs for this type of error as they would have under typical batch-processing conditions -- they could not justify the effort when "the time-shared computer could do the job so fast".⁴ While

3 The former saving typically resulted from being able to enter a program and make the several computer runs necessary to obtain results -- all within a period of one-half hour or less. The same program probably would have required several days to complete on a typical batch-processing computer system.

4 This 'different method of programming has been termed either sloppy or inefficient. It should be realized the relegation of tasks to a time-shared computer (previously done by the user in batch-processing facilities) can be quite reasonable if the savings in man-time, of this additional computer usage, outweighs the additional computer cost -- in fact, it could be termed sloppy and inefficient

respondents admitted they spent more computer time in the early stages of program writing, most felt that this was made up later when unprofitable courses of action were quickly eliminated.

The general consensus of the users was that they were doing the same type of work as they had been doing before their introduction to the facilities of Project MAC⁵, but that this work was now being done with "greatly increased effectiveness."⁶ They seemed to feel that the saving in time and the ability to access immediately the computer and receive results allowed them to explore more possible alternatives than those they would have explored if using a traditional computer system. This resulted in: (1) a more thorough analysis of their work; (2) extending the boundary of their work; and (3) redefining the "notion of what research is and is not practical".

In summary, Neisser's respondents indicated that time-sharing allowed them to solve problems more quickly, work on more complex problems, and produce "better results", but at the expense of more, and possibly less efficient, computer usage.

if the time-shared computer was not assigned certain tasks previously handled by the user.

5 However, some respondents were working in areas which could only be defined in an interactive computer environment -- such as a man-computer question and answer system.

6 This appears to have been defined as "better results, more easily, and more quickly".

Time-Sharing Research*

Of potentially greater value to an evaluation of time-sharing usage is an exploratory study attempting to compare programmers' performance under conditions of varying length of feedback delays. (Grant and Sackman, 1966). Using two different types of programming tasks, a significant saving in man hours required, but no significant difference in computer time consumed was found for one of the tasks. For the other task, the opposite results were found, that is, no significant difference in the number of man-hours, but a significantly higher consumption of computer time.⁷ These differential results indicate that the application studied may be a prime factor in determining the mix of man hours and machine minutes required to solve a problem.⁸

An informal attempt to compare usage of time-sharing and batch-processing computer systems was reported by Neisser and Saltzer. In two introductory MIT programming

7 These results were found by a re-analysis (by this researcher) of the data supplied in the Grant and Sackman report. The results indicated by that report are somewhat different -- they indicate a significant difference in overall 'debug man-hours' but no significant difference in CPU time consumed. The conflicting analyses results from differential treatments of both subjects from different populations and experimental applications with widely differing characteristics.

8 The small sample size in this study (six subjects in each group) required greater differences for significant findings than if a larger group of subjects had been tested.

* After this work was completed, a study by Schatzoff, Tsau, and Wiig was published (Communications of the ACM, May, 1967) entitled, "An Experimental Comparison of Time-Sharing and Batch-Processing."

courses a programming problem was assigned -- one-half the students were required to use the MIT Compatible Time Sharing System and the other half the traditional batch-processing computer system. It was reported that programmers assigned to the time-sharing system, when compared with the programmers assigned to the batch-processing system, consumed more computer time without saving much programmer time. (Saltzer, 1964 and Neisser, 1964)

From the cited studies, it would seem that usage of time-sharing and most traditional computer systems differs in a number of fairly easily defined ways: (1) results are returned to the user of a time-sharing system soon after he submits his input -- the traditional computer system user must normally wait an extended period of time for his results;⁹ (2) input deadlines characterize a batch-processing computer system -- time-sharing usage normally precludes such explicit deadlines; (3) the time-sharing user interacts directly with the computer, almost on a personal basis -- the batch-processing user deals with the computer through an impersonal file cabinet or an even less personal clerk; and (4) psychological and actual continuity between the user and the computer during

9 Some 'traditional computer systems' return results within a matter of a few minutes. Since this is one characteristic of time-sharing systems, the system could not truly be termed 'traditional'. Since these systems are typically under-utilized, they must be viewed under stable conditions -- which are usually saturated with long delays.

the process of problem-solving is available with time-sharing usage -- neither is available to the user of the typical batch-processing computer system.

Related Behavioral Research

The research reported below (particularly that involving interactions between a small number of persons) can lead to a better understanding of the effect of similar interactions in which one of the group members is replaced by an interactive computer.¹⁰ Although the following theory and empirical work concentrates primarily on intergroup relationships between the parties when both are human, the extension of these findings to the circumstance when one party is a computer appears reasonable.¹¹ Whether the member of a group is a person or an interactive computer, the behavior of the other group members would appear to be remarkably similar. In fact, some of the research into

10 No research has been conducted for the purpose of studying the effect of a substitution of an interactive computer for a human. The comments made here should be treated as hypotheses for research -- not conclusions based on research.

11 It is not assumed that a time-shared computer console is equal to a person in a group -- the assumption made is that a person interacting with a computer console will behave in a somewhat similar manner to that when interacting with another person. Work by Evan and Miller indicates the only major difference discovered when administering questionnaires by means of a computer console and the traditional pen and pencil (with experimenter) was the persons interacting with the computer console were somewhat more truthful in their responses. (Evan and Miller, 1966)

computer-aided instruction reported below indicates that the computer is not only able to do a better job than the human it replaces, but is more highly regarded by the persons interacting with it.

Direct interaction between persons may result in both an increased level of interaction and favorable attitudes toward the other person. As Homans hypothesized, "interaction between persons leads to sentiments of liking, which express themselves in new activity and these in turn mean further interaction. . ." (Homans, 1950).

Leavitt, using Bavelas' communication networks found that there is reason to believe that "two-way communication is more accurate than one-way. . ." (Leavitt, 1958). In related research extending this work, Cohen found that a group with centralized communications system took less time, made more correct trials, made fewer changes and fewer final errors than did a group with a less centralized communication pattern. In addition, the member of the centralized communication pattern responsible for the groups' communication and interaction had a higher level of satisfaction than did either the other members of his group or the members of the other group. (Cohen, 1964)

In a study measuring the physical rather than psychological distance between people, Festinger found a positive relationship between the physical distance between persons and sociometric choice. (Festinger, Schachter, and Back, 1950)

These findings would seem to provide support for the proposition that direct interaction with a computer -- available with a time-shared computer system -- would be expected to result in higher levels of accuracy and performance in a shorter amount of time than would a non-interactive computer system. Further, we would expect a higher level of satisfaction when the subject interacts directly with the computer.

Several studies comparing the use of interactive computers with the more traditional method of teaching seem to provide further support for these conclusions. Bilzer and Easley compared the results of using a computer to instruct students with typical classroom instruction. The researchers found the time spent on the lesson material was significantly less for the students using the computer. However, there appeared to be no measurable difference in the post-test performance scores of the two groups of students (Bilzer and Easley, 1962). In a similar experiment, Porter found that students taught spelling via teaching machines performed significantly better than students exposed to regular classroom instruction (Porter, 1959).

There are several studies which indicate that students react more favorably to machine teaching than to standard

classroom instructional methods.¹² In one, Holland studied students after completion of a one-semester course in psychology. The students were overwhelmingly in favor of the teaching machines and stated that: (1) they would have gotten less from the course if the machine had not been used; (2) they learned more on the machine than they would have had they only studied the text, given equal amounts of time and effort; and (3) they would prefer to use the 'machine' for another similar course. (Holland, 1960)

Using a time-shared computer with both typewriter input consoles and cathode ray tube display (CRT) with a light pen input, Swets found that the speed with which data were displayed, the amount of data, and the quality of data displayed did not significantly affect subject performance. He stated that "performance was not substantially improved by what appeared to be a more efficient mode of response and feedback, as supplied by the 'scope and light pen' " and concluded that "these variables were not critical". [This does not, however, prove that they would not be critical in another setting] (Swets, et.al., 1966).

Neisser concluded, based on the comments of his respondents, that one major advantage of man-machine

¹² There is not a sufficient amount of information presented to determine if the effect of the 'newness' of the machine itself was responsible for these opinions -- or if this was taken into account.

interaction in complex programming came from the ability to interact with the time-sharing system without delay on the computer's part. For support, he cited the preference of a majority of his respondents for long, uninterrupted sessions at the console (six to eight hours). A smaller group of users disagreed with this preference, however, and felt it useless to spend more than one and one-half to two hours at the console. If they couldn't correct errors in that time, they preferred to leave the problem to a later time and a possibly fresh approach. The attitude of this latter group of respondents is supported by several research studies in the area of learning. For example, Berelson and Steiner report on studies by Lorge and Hovland that indicate "periods of practice separated by periods of rest achieve much more efficient learning than do longer periods of practice with few or no interruptions. . .with the qualification that each period must be long enough to allow at least one or two complete trials, or runs, through the task." (Berelson and Steiner, 1964, pp. 159-160)

In summary, although no conclusive evidence exists concerning the value of time-sharing usage directly, there does appear to be a body of related theory suggesting that the characteristics of both man-machine interaction and time-sharing result in increased performance and a decrease in the amount of man-hours and elapsed time. A substantial

body of theory and empirical research in communications, small groups, and learning (computer-aided instruction) supports these views and findings and further indicates relationships between motivation, closeness of interaction, and performance. There are no positive findings concerning the effect of varying the quality of the response and feedback mechanisms.

CHAPTER III

Scope of the Study

This research focuses on the development of a methodology through which the characteristics of time-shared usage can be evaluated both in terms of the relative merits of different types of time-shared systems and in comparison with other types of usage -- e.g., batch-processing. This methodology will then be tested in an experimental setting designed to evaluate usage of two computer systems exhibiting characteristics of time-sharing and batch-processing. One test situation involves comparison of the effects of rapid feedback and unlimited access in a problem-solving situation. The other demonstrates the use of the methodology in investigating the effect of qualitatively different feedback upon computer programmers.

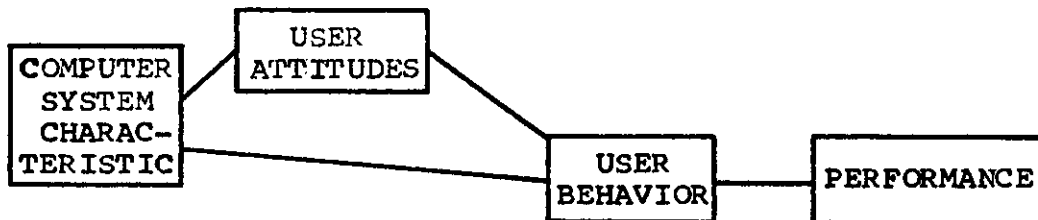
No attempt is made to determine whether batch-processing is better than time-sharing over a wide range of applications or evaluators. Rather, the test situations should be considered examples of the potential use of the methodology and the kinds of conclusions possible using the methodology in specific situations. In any event, it is unlikely that any one usage mode will be "all things to all people" so that the methodology is intended to be flexible enough to compare modes and variations in these modes over a variety of situations.

Model of Time-Sharing Usage

Although the primary purpose of this research is to develop a methodology for evaluating time-shared computer usage, it is necessary that the conceptual model underlying the research be presented as an aid to understanding the development. The research described in Chapter II suggests several categories of variables relevant to an understanding of this usage, namely those which: (1) are characteristic of a computer system under study; (2) concern the attitudes of the users of these systems; (3) are measures of users' behavior and usage of a computer system; and (4) are measures of the performance of a man-computer system. The relationship among these four categories of variables which constitute the basic model under discussion are shown in Figure 1.

FIGURE 1

MODEL OF COMPUTER SYSTEM USAGE



Computer_System Characteristics

In developing a methodology for evaluation, it is necessary to specify the kinds of independent variables which are likely to be relevant in influencing usage of these systems. Such a selection is necessarily arbitrary and cannot be exhaustive. The major independent variables to be considered here are those which have suggested themselves in preliminary research in attempting to 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 computer feedback delays; (2) differing degrees of interaction between the user and the computer system; and (3) qualitatively different response and feedback mechanisms and programming systems.

The computer's feedback delay can be measured by the elapsed time the user must wait from submission of computer input to the return of his results. Increase in these delays in the context of time-sharing systems can result in an increase in the total time required to achieve an objective and a reduction in the total productive time spent. For example, lengthy feedback delays require the user to divert his attention to another project while waiting for computer output. This can result in costly reacquaintance time when attention is returned to the original project. On the other hand, short delays encourage a user to do little thinking between submissions to

the computer, possibly resulting in shallow rather than incisive problem solutions.

The degree of interaction between the user and the computer is a measure of the number of times a user can complete an interaction¹ with the computer -- this measure can be approximated 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 something of 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 normally turn to other work while waiting for the response to his input.² Variations in the degree of interaction between the user and the computer system would be expected to affect the number of interactions possible in a given amount of time and thus the importance of each interaction.³

Rapid interaction between the user and the time-shared computer allows the implementation of a qualitatively different programming system in which the user can take an

1 User input, receipt of output, and second input.

2 It should be noted that this definition is relevant only in terms of on-line systems. The traditional batch-processing systems are, by their very nature and design, non-interactive.

3 To keep the total number of interactions constant with a varying degree of interaction, the user must alter the amount of time devoted to the task accordingly.

active part in the computing-problem solving process -- thus taking advantage of interaction between the man's heuristic superiority and the computer's algorithmic superiority. For example, programming errors discovered while executing an interactive language could be typed on a console and corrected by the user at the time of occurrence. This might allow greater flexibility in the input because the user would be available to further specify any ill-defined statements.

Users' Attitudes

The primary influence upon the users' attitudes is assumed to be the degree to which the computer system's characteristics appear to the user to facilitate or hinder him in the attainment of his short and long term objectives. The long term objectives will be those which relate primarily to solution of a task or increases in the level of knowledge of the user. Services which facilitate the submission and return of results, lower the psychological cost of using the computer system, or add to the general convenience of its use would enhance the attainment of his short term objectives.

User Behavior

When investigating usage 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 effort

expended to obtain the solution.⁴ Experience with both time-sharing and the more traditional computer usage leads us to expect shorter feedback delays will result in a problem solution requiring a shorter elapsed time for completion of a task.

Man-computer systems under study should also be evaluated by measuring the methods of usage of the various systems and the total cost of this usage. This total cost is determined by summing the cost of both the man's time and the cost of the computer's processing time for each system. We would expect that usage of some time-sharing systems will result in a lower cost of the man's time and a higher cost of the computer's time just as, in comparing time-sharing with batch-processing, we would expect higher machine cost and lower man cost in the former.

The method of usage is primarily concerned with the degree to which the user relegates programmable problem solving to the computer system. 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, in systems he perceives as more accessible. This does not really mean that such usage is more or less

4 This assumes that an acceptable solution can, in fact, be produced through the use of a computer system under investigation. If this is not true, the value of producing acceptable results must be compared with the value of doing nothing.

efficient than usage of a different computer system. Rather it indicates differential modes of rational or irrational behavior exhibited while using these systems -- behavior which should be evaluated only in terms of the final output produced.

Performance

The purpose of an evaluation of performance external to the mode of usage is to make available a measure of the output of the man-computer system which is arrived at independently of the user's behavior or the computer system used. To accomplish this objective both the output produced through the use of the computer system and a measure of the quality of the method used to obtain this output (task solution) should be evaluated by a competent evaluator according to predetermined criteria.

Methodology

The research described in Chapter II and the model of time-sharing usage presented above suggest several 'evaluation functions'⁵ for inclusion in a methodology for evaluating computer system usage. Those which are considered relevant are: (1) the cost of using the system; (2) the performance produced through the use of the computer system; (3) the speed with which results can be

5 By an 'evaluation function', we mean a descriptor whose use is generally accepted as relevant to an evaluation of a situation under study -- e.g., performance, etc.

produced; (4) the amount of learning resulting from the use of the computer system; and (5) the attitudes of the users of the system.

These evaluation functions and a method for providing operational definitions for them are discussed below. No a priori assumption is made as to 'weights' which should be applied to these functions to obtain an evaluation index for any given situation. These evaluation functions and the methods presented for obtaining operational definitions should provide a basis for conducting a comparative evaluation of computer system usage.

Computer System Cost

The costs incurred in using a computer system to solve a problem are contributed primarily through the expenditure of a man's time and a computer's resources.⁶ It will be most convenient to look at these constructs in terms of a simple algebraic expression. Operationally, this computer system cost can be expressed as:

$$C = R_m \times V_m + R_c \times V_c$$

6 In addition to this 'direct' cost of computer system usage, an 'indirect' cost can result from the effect of differential performance and/or speed of problem solution. Since measurement of these factors is not normally quantitative, no attempt will be made to include them in the calculation of computer system cost. They will, however, be discussed under the appropriate sections of the Methodology below.

where: C is the total 'direct' cost to produce a problem solution.

R_m is the amount of the man's resources (or time) expended.

V_m is the value of each unit (hour) of a man's resources expended.

R_c is the amount of computer system resources expended.

and V_c is the value of each unit of the computer system's resources expended.

The man's resources (R_m) can be easily measured as the amount of his time expended to obtain and make use of a problem solution. The value of this resource (V_m) is not quite as easily defined. In a perfect market, the value of a resource would equal its marginal productivity -- a measure not easily defined in a complex environment. Even more difficult is the determination, or even an approximation, of this marginal productivity in the imperfect market economy that does exist. Supply and demand functions do not always operate according to classical assumptions -- the supply of people with specialized training may be limited and not subject to strict economic motivations. Under these conditions, the value of an additional hour's use of this resource may far exceed the cost of providing this additional hour's resources. Whereas in the perfect market economy the use of the average cost can provide an adequate approximation to the marginal productivity, its use here may not be an acceptable approximation to the resource's value. Since no direct

measure -- other than the resource's cost -- is typically available, empirical determination of an acceptable substitute may be necessary. This can be approximated through investigation of the maximum amount that would be paid for either an extra hour of a man's time or of a full-time extra man -- independent of all other factors such as a prevailing level of reimbursement.⁷

The computer resources expended (R_c) can be measured by the amount of the computer system's central processing unit time charged to the task. It should be recognized that the use of this measure may not accurately reflect any one user's utilization of all components of the computer system.⁸ Research in progress is attempting to introduce other factors -- such as the use of mass storage, quantity of output, and degree of interaction -- into the method of charging for this usage. However, both philosophical problems of allocation of system components between the user and the system overhead and the practical problems of measurement have retarded the development of a viable method of charging in proportion to the actual usage of the computer system. The value of the computer

7 Further determination of this resource's value is beyond the scope of the present work.

8 Use of this measure may be particularly misleading in current large-scale computer systems where the cost of the main computer processing unit is typically less than fifteen percent of the total system cost.

system (V_c) for each unit of resource expended will be based on the long run cost of the computer system.⁹ This value (or cost) will be bounded, at the lower end, by the average cost of renting (or purchasing) an entire computer system and, at the upper end, by the cost of purchasing a small amount of computer resources.

To compute the cost breakeven point for two computer systems, the expression for the cost of one system can be set equal to the cost for the other and solved for the variable desired. If the subscript 'a' is used to signify one computer system and 'b' the other, the cost of the two systems can be expressed as:

$$C_{a'} = R_{m'a'} \times V_{m'a'} + R_{c'a'} \times V_{c'a'}$$

and $C_{b'} = R_{m'b'} \times V_{m'b'} + R_{c'b'} \times V_{c'b'}$

Solving these equations for breakeven cost by equating the two functions yields:

$$R_{m'a'} \times V_{m'a'} + R_{c'a'} \times V_{c'a'} = R_{m'b'} \times V_{m'b'} + R_{c'b'} \times V_{c'b'}$$

If we assume that the resources provided by system users are equal, the quantity $V_{m'a'}$ can be set equal to $V_{m'b'}$.

9 Arguments that the 'cost' of using this 'capital good' is equal to its marginal cost of operation may be workable in the short run but neglects an important long run problem -- that of providing for necessary expansion or replacement of the facilities.

This gives:

$$V_m \times (R_{m'a'} - R_{m'b'}) = R_{c'b'} \times V_{c'b'} - R_{c'a'} \times V_{c'a'}$$

This expression can be further simplified by expressing the value of one computer system in terms of the other:

$$V_{c'a'} = \underline{a} \times V_{c'b'}$$

where "a" is the ratio of costs of computer system 'a' to computer system 'b'.

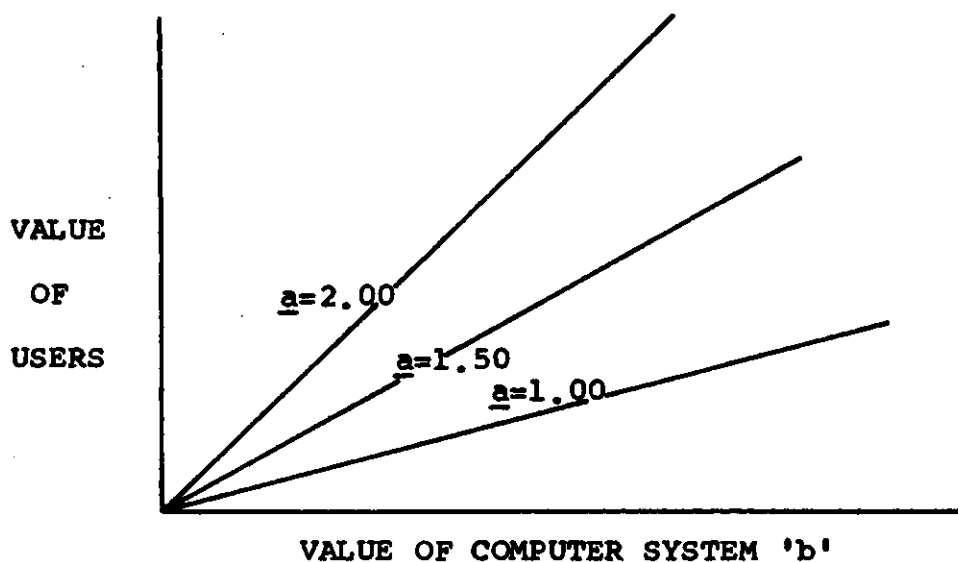
$$V_m \times (R_{m'a'} - R_{m'b'}) = V_{c'b'} \times (R_{c'b'} - [\underline{a} \times R_{c'a'}])$$

The amount of computer system time and man time required to perform a task can be experimentally determined. Numeric quantities for any of the three remaining variables -- the value of the man, the value of computer system 'b', or the ratio of the values of the two computer systems -- can now be expressed in terms of the other two variables.

Figure 2 demonstrates the use of a graph to simultaneously display all three variables. The vertical axis represents the value of the man and the horizontal axis the value of computer system 'b'. Each line segment represents a different value of "a". Values of V_m which define a point above the appropriate "a" line segment indicate lower total system cost would be achieved through the use of computer system 'a' -- values below that line indicate costs favorable to computer system 'b'. Notice that with a given ratio between the costs of the two com-

puter systems, only one line segment is relevant to the analysis -- the several line segments pictures in Figure 2 indicate different possible ratios of these system's costs.

FIGURE 2
RELATIONSHIP BETWEEN VALUE
OF USERS AND COMPUTER SYSTEM



Performance

If output resulting from use of a computer system fails to attain some minimum level of performance, the use of this computer system must be labeled 'unacceptable'

and eliminated from further evaluation.¹⁰ Alternatively, output which does attain this minimum level of performance can be further evaluated to allow investigation of the relationship between performance of various computer systems and the resources which must be expended to attain this performance. Various constraints can be imposed on the system to study the man-machine system under conditions that would normally be encountered. By constraining the total resources available, the level of performance at a given cost can be studied. However, if only one of the two inputs to the resources -- e.g., machine time -- is constrained, the relationship between utilization of the other resources and performance is available for study. By specifying the level of performance desired, the relationship between performance and the total cost, as well as between performance and allocation of resources between man and the machine cost, can be studied. If no constraints are imposed, a study can be made of the amount of resources and time that will be expended by the users of the computer system -- a measure that will indicate the value they assign to the resources expended.

Before presenting the 'performance' evaluation function, it should be recognized that data resulting from this evaluation may not be measurable on a ratio or even

¹⁰ Unfortunately, the first step many persons would take in such circumstances would be to re-evaluate this minimum level of performance. Instead, a sufficient amount of effort should be expended in the original process of determining 'acceptable' performance criteria so no re-evaluation could be justified.

an interval scale -- this can have an effect on the types of conclusions that may be drawn. For example, the evaluation must be measurable up to a ratio scale in order to draw conclusions of the type: "Performance is X% of the optimal performance level with computer system 'A' ". Ordinal data can only be used to draw directional conclusions, i.e., 'results are better than [or less than, or equal to] some pre-defined measure', while data defined up to an interval scale can be used to evaluate the size of the difference between systems, but not as a proportion of some absolute level.¹¹ Other uses of these data could easily lead to erroneous conclusions.

Because this process of measuring 'performance' will not normally result in ratio data, no determination of the performance in terms of 'productivity' (input/output) will be possible. As a result, the 'performance' measure will not be introduced into the 'Computer Ssystem's Cost' function in the previous section. However, by establishing criteria for 'acceptable' performance, 'satisfactory, performance, etc., the level of performance can be indirectly introduced into this cost function by measuring the resources expended by the various computer systems to achieve equal levels of performance.

¹¹ See, for example, Siegel (1956).

FIGURE 3
RELATIONSHIP BETWEEN PERFORMANCE
AND VALUE OF RESOURCES EXPENDED

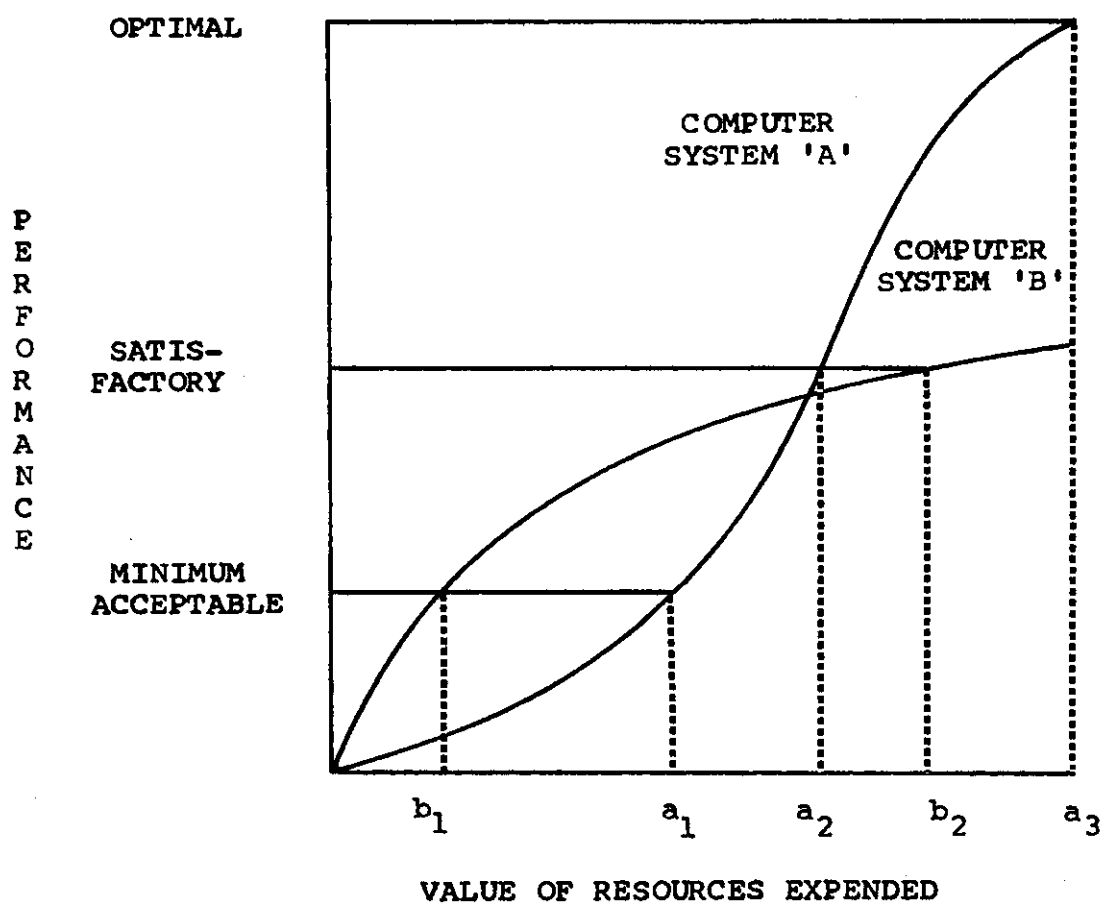


Figure 3 displays the relationship between performance level and resources expended for two hypothetical computer systems.¹² The definition and use of several performance

¹² It is also reasonable to study the relationship between 'performance' and each individual component of the resources. However, this would appear to fit better into the section investigating the users' attitudes and behavior.

levels at which to measure the resources expended allows a more comprehensive understanding of the relationship than would measurement of either final performance or minimum acceptable performance alone. This scheme will also indicate if the rate of progress and the level of performance differ radically as a function of the resources expended. It is probable that taking measurements of resources expended and performance attained would not give the same results as giving different users different deadlines; from the standpoint of practicality, however, it is probably not worthwhile to draw too great a distinction here.

With Figure 3 as a guide, it can be seen that a determination of a 'better' computer system may depend on the level of performance required as well as constraints placed on the system. For example, in Figure 3, computer system 'B' outperforms computer system 'A' until more than X units of resource are expended -- far past the level of 'minimum acceptable' performance. From this point on, computer system 'A' becomes more productive and is the only system whose performance attains the 'optimal' level with any reasonable expenditure of resources. If asked which computer system is 'better', the only reasonable answer would be to request the resources available or the level of performance required -- without one of these, any response would be meaningless.

This example was not presented as indicative of any two specific computer systems, but rather to demonstrate

the methodology to be used and to highlight difficulties in applying it. With this methodology, the introduction of constraints is easily handled as will be demonstrated in Chapter IV. The minimum cost solution to the problem, which must occur concurrent with the minimum acceptable level of performance, clearly is achieved through the use of computer system 'B'. However, maximizing the performance level -- subject to some resource constraint -- occurs with computer system 'B' if this maximum cost is less than an expenditure of X units of resource, or with computer system 'A' if the resources available are greater than X units. With no resource constraints, it would appear that computer system 'A' is the more preferable -- in addition to the higher level of performance after the expenditure of X units, computer system 'A' also appears to permit a higher final level of performance than computer system 'B'.

In general, several performance level indicators could be defined, and the expenditure of resources needed to attain these levels measured and then used as input to the cost evaluation function as above.¹³

13 Although the above has referred to the cost of developing a computer system application, it should be understood that consideration must be given to the entire life of the application -- which includes its use. For example, it is generally agreed that use of an assembly language for computer programming will normally result in a higher cost to develop the necessary program than would the use of a compiler language. However, use of the assembler would typically result in a computer program which would consume fewer computer resources with each use than would a

Speed of Problem Solution

The 'Speed of Problem Solution' is defined as the amount of elapsed time necessary to provide a suitable solution to a task.¹⁴ Implicit in the discussion of this topic is the notion that a decrease in the value of the solution will take place as a result of an increase in the amount of elapsed time. At the same time, this increase in the amount of elapsed time will probably generate an increase in the amount of resources expended although if the time constraint is very restrictive, wasteful use of resource can result. Normally, increased expenditure of resource should result in some increase in the level of performance -- or the 'value' of the output. The problems and methods of both measuring the 'Speed of Problem Solution' and integrating the changes in output value and resource expenditure into both the Computer System Cost and the Performance evaluation functions are discussed below.

Before investigating the effects of the 'Speed of Problem Solution' on both computer system cost and performance, methods of determining elapsed time must be investigated. Although the generally accepted meaning

compiler-produced program. If the program is used frequently enough, the savings resulting from its more efficient operation may more than offset its higher development costs.

14 A 'suitable solution' was discussed in the previous section on 'Performance' evaluation.

of 'elapsed time' specifies the duration from the initiation of a task to its completion, this does not provide sufficient definition or specification to determine what is really meant by either initiation or completion. The time of task initiation may be accepted as either the time of task assignment or the time work is actually begun. In the same way, the time of task completion could refer either to the time the user considers the task completed or to a deadline beyond which a problem solution would no longer be acceptable.

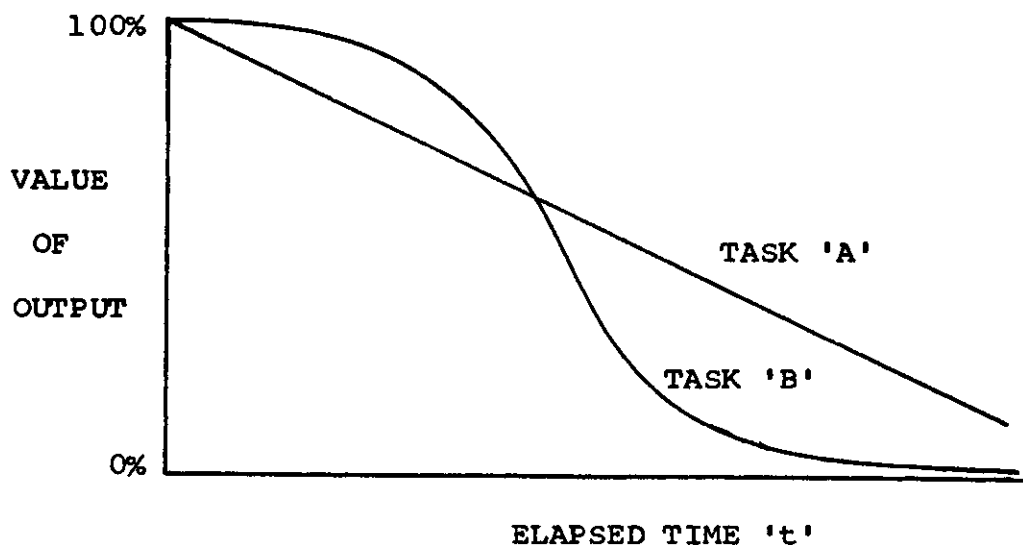
The specification of appropriate measures will depend upon requirements for providing solutions. If either a deadline exists or some not insignificant value is associated with a 'quicker' solution, the 'elapsed time' should be measured as the period of time from the initial assignment of the task to its completion. If neither of these characteristics is present, the 'elapsed time' should be measured as the amount of time the user appropriates to the task. This would not include time from the assignment of the task until effort is first expended. In addition, any substantial blocks of time devoted exclusively to other tasks would not be included. Measuring the time from start to finish for a task continuously worked on probably gives the minimum amount of elapsed time that must be expended to solve a task. Assuming that rest and freedom from psychological set probably outweigh the deleterious effects of

forgetting (if the span between sessions at the computer is not too long), the measurement of time spent on the task -- using the second method above -- will give a higher or lower figure depending upon how "substantial blocks" of time are defined.

The relationship between increased elapsed time and decreased value of the output, i.e., where the timely presentation of results is critical, is a very important one. Except for a few cases in which this decrease in value is negligible, the 'Speed of Problem Solution' must be introduced into a total evaluation function as a method for maximizing the value of the output subject to constraints or costs imposed by the additional elapsed time. In Figure 4 are shown two examples of this decrease in value of output as a function of elapsed time.

FIGURE 4

VALUE OF OUTPUT AS
A FUNCTION OF TIME



Task 'A' in Figure 4 displays the output value as a function of time for an application with a constant rate of loss of value as a result of a delay in output. Task 'B' is an application evidencing a loss of value which, at the 'deadline', becomes significantly large.

If we assume that V_0 is the maximum value of the output if produced at time t_0 , then the value of this output at time 't' is:

$$V_t = V_0 \times f_t$$

where f_t describes the relationship between the value of the output and the elapsed time. This function could, for example, be a negative exponential function of $[t-t_0]$ which represents a rapid "decay" in value after a deadline t_0 , and equal to V_0 for 't' equal to (or less than) t_0 .¹⁵

A secondary effect of a change in the required 'Speed of Problem Solution' might be to change the value of output. In other words the maximum attainable value, V_0 , might be a function of t_0 . At the same time, however, an increase in elapsed time probably produces the expen-

| | | | |
|----|---------|----------------------------------|--------------|
| 15 | Suppose | $f_t = e^{-a(t-t_0)}$ | |
| | Then: | $V_t = V_0 \times e^{-a(t-t_0)}$ | if $t > t_0$ |
| | | $= V_0$ | if $t < t_0$ |

would permit the value of V_t to vary from a maximum of V_0 to a minimum of zero as t grows large.

diture of additional resources. For example, the use of an increased amount of elapsed time will typically reduce the value of the delayed output and result in the expenditure of additional resources. However, the extra time might be expected to increase the level of performance and perhaps its value.

This increased level of resource expenditure can easily be measured by techniques previously presented. However, as mentioned in the 'performance' section above, the assigning of an absolute value to the performance is typically impossible -- comparative methods must be used. Using the measures of performance developed, e.g., 'acceptable', 'satisfactory', etc., the marginal value of an increase in level of performance could be approximated by experimentally determining any changes in the level of resource expenditure that would be incurred to achieve this higher level of performance, independent of the time required to produce these results. A similar method could be used to determine the marginal cost, or loss in value, of delaying the problem solution.

The 'Speed of Problem Solution' can be integrated with the evaluation functions for both Computer System Cost and Performance by setting the net marginal value of the output -- the gross marginal value of the 'better' output less the marginal loss in value resulting from delayed output -- equal to the marginal cost of expending extra

resources. The marginal amount of elapsed time that should be expended will result from this process.

Learning

Under some circumstances, the principal output desired from computer system usage is not of the traditional computational form, but is rather a change in the user -- as in teaching with the aid of a computer system. In such cases, traditional output would be important only in its contribution to effecting the desired change in the user.

That 'Learning' may be treated as a subject of the 'Performance' evaluation function can be seen in the means of measuring 'Learning': (1) the total amount of learning evidenced in a given amount of time; and (2) the amount of time necessary to achieve a specific amount of learning. The problems of measuring the level of learning achieved are quite similar to those involved in measuring performance -- in most cases the form of the data will not allow numerical evaluation. As a result, the method that will be used for measurement will parallel that used for the 'Performance' evaluation function: several levels of 'Learning' will be defined, and the amount of elapsed time and resources necessary to attain these levels will be determined. These will then be used as inputs to the evaluation function for computer system costs to determine the comparative cost of achieving various levels of learning.

Users' Attitudes

The Users' Attitudes have been presented as one of the dependent variables which influence the users' behavior and usage of computer systems. At the same time, they appear to serve a second function, that of a surrogate for the harder-to-measure, "propensity to use" a computer system. For example, if one computer system is perceived to be more valuable, i.e., easier to access or use, more productive, etc., than another computer system, it would be expected that the demand for, or usage of, the first system might increase relative to the second. In particular, attitudinal measurements will provide one basis for forecasting the short term demand for a particular type of computer system and, potentially, the long run demand for all computer facilities. The latter is predicated upon the assumption that users who view a computer system more favorably will perceive a lower 'psychological cost' to use it than a system not so perceived. This long term change in demand will result from: current users' expansion of the scope of their work; and the expansion of the user group itself through the influx of persons who presently perceive the 'cost' of learning about and using a computer system to be too great.

Users' attitudes can be comparatively measured along several dimensions: (1) the usefulness of the computer system; (2) the ease of access to the computer system; and

(3) the value of the output obtained while using the computer system. These attitudes can be collected through the administration of questionnaires both before and after experimentation and the measurement of the changes in these attitudes resulting solely from the experimentation. This technique should eliminate any bias inherent in the user at the onset of experimentation. This 'change score' method is difficult to administer if the subject is unable to evaluate one of the above dimensions, e.g., if the user has no expectations concerning his output before experimentation, it might be meaningless to obtain a 'before' score. In such cases, the single 'after' score must be used.

CHAPTER IV

Introduction

In this chapter two experiments are described which use the methodology described in Chapter III to test certain hypotheses concerning behavior. In presenting these experiments it is recognized that two distinct sets of items are under test. First, the experiment is intended as a test of methodology. Second, the results may be interpreted as a test of hypotheses provided that one accepts the methodology as given. For convenience, the experiment will be presented in the form dictated for behavioral research and comments on the methodology will be reserved for later chapters.

Experimental Design

Based on the objectives of this research, it was decided that the research setting, experimental task, and experimental subjects should approximate 'real-world' conditions as closely as possible. To these ends, an experimental setting combining the laboratory experiment's controllability with the field study's observability was desired. The other major requirement of the experimental setting was the ability to manipulate the feedback delays and feedback quality independently of each other to allow separate investigation of the two major characteristics which are said to differ between time-shared and the more

traditional computer settings.

Two settings were selected for this research: (1) a graduate course in Industrial Dynamics (Forrester, 1962); and (2) an introductory course entitled Management Information Systems. Both courses had the advantage of making extensive use of a computer system during the semester's work. The first course used the DYNAMO system (Pugh, 1963) on both time-shared and batch-processing facilities. The second used an IBM 1620 computer system exclusively, but had available several FORTRAN-compatible systems of varying feedback qualities.

The Industrial Dynamics course was selected for this research because it utilized a computer system in the development and analysis of complex simulation models. From such analyses, "management policies" would be designed and used to alter the model's behavior. With the programming required for the simulation model, this application appeared to be more representative of possible future uses of interactive computer systems than one based solely on a programming task. The DYNAMO language also had the advantage of being one of the few programming systems available with exactly the same characteristics whether used on time-sharing or batch-processing computer systems.¹ This

¹ This experimentation was carried out using the Project MAC Compatible Time Sharing System (CTSS) developed at M.I.T.

feature was especially attractive in that it allowed investigation of the effect of different feedback delays and different degrees of interaction while maintaining a constant 'quality' of feedback.²

The Management Information Systems course was also included in the research because it allowed investigation of the effect of providing differential feedback 'quality' while maintaining equal feedback delays and interaction rates -- the other half of the hypothesized advantages of time-sharing. In order to provide this differential feedback 'quality', two FORTRAN-compatible programming systems were made available: (1) FORTRAN II was provided with the computer system and supplies minimal error checking during execution; and (2) FORGO is an interpreter which supplies extensive error checking and excellent diagnostics during program execution -- features not found in the version supplied with the computer system. It was expected that the differences in error checking and diagnostic messages between the two systems would be sufficiently great to allow measurement of any significant

² It should not be assumed, based on this experimental design, that time-sharing systems of the future will be the same as batch-processing systems -- but in an interactive environment. Whether or not this will be true, the primary purpose of using the same systems on both types of computer systems was to effectively study the effect of differing feedback delays -- unconfounded by other variables.

differences in the use of the computer system.³

Selection of Subjects

The subjects in each experimental setting were the course's students. After eliminating about ten percent of the subjects from the study (for various reasons) before the onset of data analysis, approximately sixty subjects remained in the experiment using the Industrial Dynamics course and sixty-five in the Management Information Systems course. Of these, over seventy percent were either juniors, seniors, or graduate students in management at M.I.T. The remaining subjects were primarily graduate students from other fields at M.I.T.

At the beginning of the semester in which the experimentation occurred, the students in each course were required to complete a background questionnaire.⁴ Based on these responses, a matched pairing of students was carried out, and then one member of the pair assigned randomly to one of the two experimental treatments -- the other one, of course, was assigned to the remaining treatment. This technique was used to assure both a random and equal division of subjects into treatments.

Experimental Tasks

The students in the Industrial Dynamics course were given, as an assignment, a 'case study' involving the

analysis of market dynamics in a 'Construction Industry'. Each student in the course was required to complete the programming of the simulation model of this 'industry', debug the model, analyze the output, and design a decision-rule, based upon his analysis of these market dynamics, which would maximize the profits of a small-scale independent builder within the industry. The students were notified that a report and their results would be due in approximately ten days and that their grade for the assignment would be based equally on: (1) the profits produced by the model, and (2) their understanding of the dynamics of the model and the quality of their decision rule. The latter grade would be based on the report submitted at the end of the assignment and the former would be measured directly from their computer output.

The Management Information Systems course required the programming of a typical accounting and inventory control system for a manufacturing company. The students were notified that their grade would be primarily based on the computer program they produced but the accompanying report would have secondary influence. Approximately eight weeks were allowed for completion of the assignment.

Experimental Procedure

The experimental tasks were presented to the students as part of the normally required course assignment. While assigning the problems, the instructors notified the stu-

dents that a research group (in the case of the Industrial Dynamics course, the 'Industrial Dynamics Research Group') was involved in a study of some aspects of computer usage and would, during the (then) upcoming assignment, be collecting data concerning the methods used by the students in completing the assignment.

Each student was notified of his assignment to use either the time-sharing or batch-processing computer system⁵ concurrent with distribution of the homework assignment. After receiving the problem, but before using the computer, the students were required to complete a questionnaire. In addition, the students were requested to complete a short questionnaire after each use of the computer.

Members of the Industrial Dynamics course using the batch-processing system were able to submit as many as two sets of computer runs daily for a maximum of twenty sets during the course of the experiment.⁶ The students assigned to use the time-sharing system had access to the computer from ten in the morning to midnight for the ten days of the assignment.

In the case of the Management Information Systems course, time on the Sloan School of Management's IBM 1620

5 In the case of the Management Information Systems course, either of the two FORTRAN-compatible programming systems.

6 They could submit as many different versions of their simulation model as desired with each set of input.

computer was reserved for several periods during each day in addition to normally scheduled service runs. There was no problem of discriminatory service since the same computer was equally available and any restriction of this access would have affected the two experimental groups equally.

Data Collection

Both the questionnaires completed by the students during the assignment and analysis of the computer input and output of each student were used to provide data on the users' attitudes, behavior, and computer usage. Both methods were employed to: (1) discover how each student solved the assignment; and (2) provide a method of verifying important data by providing logical cross-checking wherever possible.

There were several types of questionnaires. First, a pre-experimental questionnaire was designed to gather background information at the beginning of the semester in which the research took place.⁷ Second, a questionnaire completed before the students made use of either computer system was used as a 'before' measure in the investigation of attitude change caused by their use of either computer system.⁸ Third, after the subjects analyzed each interaction with the computer, a question-

7 A complete set of these questionnaires will be found in Appendix B. These will be ordered as presented here.

8 It would, additionally, allow further verification of initial population characteristics.

naire investigating attitudes, progress, time expended, and type of work done was administered. A fourth type of questionnaire, completed when the student handed in the assignment, was designed to gather data concerning many of the above measures for the entire period of the experiment.

The following specific information was collected through questionnaire and/or content analysis of the printed output: (1) the amount of time expended on the experimental task and a measure of when, during the experiment, the time was expended; (2) a breakdown of the time spent into categories, such as analyzing results, making changes in the program, waiting for return 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 output; and (7) student's evaluation of the 'effectiveness' of each run's output.

Hypotheses

The following hypotheses are presented to aid in the investigation of user behavior. The principal focus of this section will be to present hypotheses directed at user behavior under conditions of varying speeds of output feedback and rates of interaction, i.e., the Industrial Dynamics experimental setting. A secondary

focus will concentrate on those aspects of user behavior expected to demonstrate changes as a result of the varying quality of feedback -- this section will present only those areas hypothesized to conflict with the principal setting. It should be emphasized that these hypotheses relate to the specific experimental settings under study, and the results obtained are generalizable to other applications or systems only to the extent that the experimental settings are generalizable.

Support for the following major hypothesis concerning behavior, within the Industrial Dynamics experimental setting, is provided by both behavioral theory and research and preliminary experimentation:

As a result of the faster feedback of output and a higher degree of interaction available with the time-shared computer system than the traditional computer system, the time-sharing users will exhibit more favorable attitudes toward both the usefulness of the system and the value of the output. These users' attitudes will combine with the computer system characteristics and result in a higher level of performance, sooner, and at equal or lower cost than possible with use of a traditional computer system. Finally, use of the time-shared computer system will result in a greater change in learning than with use of the traditional computer system.

Computer System Costs

The resources, or time, of the computer and its users provide the principal input to the cost of computer system usage. The behavioral theory and research and preliminary experimentation leads us to expect that faster feedback of

output and a higher rate of interaction will result in the user expending an increased amount of computer resources -- resources which have a higher rate of cost than those on a traditional computer system.⁹ Concurrently, we would predict use of time-sharing would result in a decrease in the rate of expenditure of user resources required as a result of a decrease in both the programmable tasks required of the user and in the amount of reacquaintance with the task. Although the cost of using the interactive system depends upon the balance between these charges, we would hypothesize that this cost will not exceed the cost of using the traditional computer system. A further hypothesis suggests that this cost will be less than that for usage of the traditional computer system.

Hypotheses:

- (1) The use of the time-shared computer system under conditions of faster feedback of output and a higher rate of interaction will result in a greater amount of computer processing than corresponding usage of a traditional computer system. However, this usage will require a lower rate of expenditure of the users' resources.
- (2) The total cost of interactive computer system usage (for equivalent levels of performance), will not exceed the corresponding cost of using the traditional computer system -- and may be less than the cost of such usage.

9 Present experience indicates the cost of interactive computer system usage is between fifty and two hundred percent higher than the cost of an equivalent amount of computation on a traditional computer system, for reasonably implemented time-sharing systems. This higher rate of charging will be considered in the pricing of resources.

Performance

As mentioned in Chapter III, the 'performance' of the man-computer system, a measure of the value of the output produced, must be evaluated independent of the specific computer system or the amount of its resources expended. The literature cited suggested that time-sharing usage will: "improve the ability to program" (Corbató, Daggett, and Daley, 1962), "Open up several new forms of computer usage" (ibid), and "increase (the) productivity of computer catalyzed research'..." (Dennis, 1954). The preliminary experimentation and other research appear to provide an indication that the use of time-sharing does allow the user to produce 'better results', e.g., if the task in question is to analyze a problem and produce a decision-rule, the user of the time-sharing system is able to produce a measurably better decision rule; if the task is to produce a program whose results are more often correct, which does more checking of inconsistencies in the data, or which is more completely documented, the user of the time-sharing system will produce a more finished program.

Hypotheses:

- (1) The output produced by the user of the time-sharing system will exhibit a higher level of performance than that produced by the user of the traditional computer system.
 - (2) An evaluation of the methods used to produce this output will demonstrate a higher level of understanding of the problem -- independent of the level of performance -- by the users of the time-sharing system.
-

Speed of Problem Solution

The measurement of the Speed of Problem Solution is relatively easy if work is progressing on only that one task. However, this assumption may not be very realistic except under very simple task conditions.¹⁰ Under the more realistic conditions of multiple, non-trivial task demands upon the user, we would expect these shorter feedback delays to have reduced influence in determining the elapsed time required to complete the task than under the trivial conditions, i.e., in the complex environment, a given task will not normally have priority over all other tasks for the entire time it is active -- this will reduce the responsiveness to shortened delays.

For the hypothesis presented below, the phrase "everything else equal" is implied. It is clear that testing of this hypothesis is valid if the performance achieved by the users of the time-sharing computer system is not less than that of the traditional computer system users -- such output would tend to result in a conservative analysis. However, if the opposite conditions occurred, i.e., the performance level of time-sharing users was less than that of the batch-processing users, testing of the hypothesis would be meaningless -- we would be uncertain if the "faster" Speed of Problem Solution was caused by the user of the time-shared computer system or by the

¹⁰ In addition, there is sufficient evidence to suggest that continuous work on a task is inefficient.

lower level of performance achieved.

Hypothesis:

- (1) The use of a time-shared computer system will result in a faster rate of problem solving than that obtained with a traditional computer system.

Learning

With the specific application chosen for study, we would expect two different types of changes in the users' experience to occur -- one involving use of the DYNAMO programming language, and the other involving the use of Industrial Dynamics. Use of DYNAMO approximates traditional computer programming experience while use of Industrial Dynamics is more typical of unprogrammed problem-solving. We would expect the opportunity to relegate a large number and percentage of the programmable and clerical tasks (such as checking for errors) to the time-shared computer system while concentration of the user's attention on non-programmable tasks (such as analysis of logical errors and decision-making) would result in a greater change in experience for the time-sharing user than the traditional computer system user.¹¹ As the application tends toward the programmed area, we would expect this relegation of tasks to the computer would become less frequent and result

¹¹ This is one of the areas in which a supposedly inefficient division of labor, as indicated by this differential behavior which results in increased computer usage, might make a positive contribution to the total system.

in a decrease in the differential Speed of Problem Solving for the two types of computer systems.

One primary advantage of the opportunity for the user to interact continuously with the time-shared computer system is the facility to produce a logically consistent amount of work without interruption. Use of this type of computer system should result in a greater amount of learning than with a computer system which allows only one interaction with a computer during an extended period of time.

Hypotheses:

- (1) The use of a time-shared computer system will result in a greater increase in the level of experience through the relegation of programmable tasks to the computer.
- (2) The opportunity afforded by time-shared computer systems for continuous interaction will result in a greater amount of creative learning.

Users' Attitudes

We would expect more favorable attitudes toward the computer system which provides faster feedback of output and a higher degree of interaction. In addition, we would expect the output produced through the use of this computer system to be viewed more favorably than the traditional computer system output.

The users' attitude should not be construed as an end in itself but, rather, as a variable which affects the users' behavior and, in turn, the usage of the computer system. Users' attitudes can serve as a means of

shifting the short term demand for computer systems by altering their viewed 'cost' of use during the process of use. These attitudes can even change the long term demand for all computer systems by altering the viewed 'psychological cost' of accessing computer systems. In both the short and long run, we would expect time-sharing computer systems to be viewed more favorably than traditional computer systems -- primarily as a result of the faster feedback of output and higher rates of interaction available with them.

Hypotheses:

- (1) Use of the time-shared computer system will result in a greater positive change in attitudes toward the usefulness and value of the computer system than of the traditional computer system.
- (2) Use of the time-shared computer system will result in more favorable attitudes toward the output produced than of the traditional computer system.

Management Information Systems

In most ways, the hypotheses relevant to the introduction of differential qualities of feedback, in the Management Information Systems experimental setting, parallel those relevant to differential speeds of feedback of output and rates of interaction, in the Industrial Dynamics experimental setting. In this section we will present the one important area in which the effect of the two sets of computer system characteristics might be expected to produce contradictory hypotheses -- the amount

of computer resources expended.

We would expect the 'higher quality' of feedback to result in a greater amount of work being done during each interaction with the computer system. This should result in a decrease in the number of computer interactions required to attain a given level of performance, and a corresponding decrease in the total amount of computer resources required to attain this performance level. We would also expect a corresponding decrease in the total amount of the users' resources expended.¹²

Hypothesis:

The use of a higher quality of output will result in a decrease in the amount of both the system's and the users' resources required to attain a given level of performance.

¹² A corollary of this could hypothesize an increase in the performance level for corresponding resources expended. This will not be done because we wish to emphasize the decrease in the expenditure of computer resources.

CHAPTER V

Introduction

The testing and validation of the methodology for evaluating time-shared computer system usage is the primary goal of this research. Since this requirement necessitates, among other things, experimental settings relevant to the 'real-world', this research allowed the investigation of the effects of the designed settings on the behavior of relevant users as a secondary goal. As a result, the analysis will be presented in two distinct sections; the validation and application of the methodology, and those behavioral results which are outgrowths of the basic experimentation. The first of these will include the evaluation functions for Computer System Cost, Performance, Speed of Problem Solution, Learning, and Attitude, while the second will investigate decision-making strategies and the rate of change of performance. Before presenting these results, two preliminary issues related to both the Industrial Dynamics and the Management Information Systems experimental settings must be presented: the comparability of the subject populations and the characteristics of the computer systems used.

Characteristics of the Subject Populations

The pairing and randomization technique used to construct experimental groups were devised to match the groups on the variables listed in Table 1. (See Appendix B for questionnaires) Statistical analysis of the subjects' responses (approximately six weeks before experimentation) gave no indication that members of the control and experimental groups came from populations which differed on these variables.¹ This should not be construed as a test of population characteristics however.

TABLE 1

VARIABLES USED TO CONSTRUCT
EXPERIMENTAL AND CONTROL GROUPS*

Academic Department

Year in College

Previous Experience with:

- a) Industrial Dynamics
- b) DYNAMO language

Number of Computer Courses Taken

Previous Experience with:

- a) Batch-Processing
- b) Time-sharing

* As an example of the effectiveness of the partitioning, analysis of the least matched variable, the "Number of Computer Courses Taken" resulted in a significance level of $P[2\text{-tail}] > 0.80$ for a Chi-Square of 1.45.

1 Similar techniques were used to construct the experimental groups for the Management Information Systems experimental setting. There appeared to be no basis for believing the subjects came from different populations.

As a measure of initial population characteristics, subjects were required to complete a questionnaire just prior to the onset of experimentation. Questions concerned users' experience with both the subject of the course and the associated programming language, their experience using the programming language on both computer systems, and their evaluation of both computer systems in helping them to analyze problems in this field. Analysis of their responses, as presented in Table 2, provides no basis for differentiating between the two experimental groups.²

TABLE 2³

ANALYSIS OF INITIAL
POPULATION CHARACTERISTICS

| | <u>U</u> | <u>P[2-tail]</u> | <u>N</u> |
|--|----------|------------------|----------|
| Experience writing DYNAMO programs | 364 | .26 | 30, 29 |
| Experience analyzing Industrial Dynamics problems | 377 | .36 | 30, 29 |
| Experience using DYNAMO on the Batch-processing computer system | 199 | .46 | 19, 23 |
| Estimate of the value of the Batch-processing system in helping analyze Industrial Dynamics problems | 76 | .98 | 11, 14 |
| Experience using DYNAMO on the time-sharing computer system | 413 | .73 | 30, 29 |
| Estimate of the value of the Time-sharing system in helping analyze Industrial Dynamics problems | 320 | .23 | 28, 28 |

2 For all cases, the two-tailed significance level was greater than 0.23 -- a significance level of approximately 0.05 or less would normally be required for rejection.

3 Meaningful results will be reported as one-tailed levels

Computer System Characteristics

The computer systems used in the experimental settings must be investigated to verify that the characteristics of the 'experimental' system were clearly differentiated in practice, as well as in theory, from the characteristics of the 'control' system.⁴ For the Industrial Dynamics experimental setting in which both time-sharing and batch-processing computer systems were used, the characteristics which differentiated the two systems were the output feedback delay time and the rate of interaction. For the Management Information Systems experimental setting in which one computer system was used with two different programming systems, the sole experimental manipulation was the difference in the quality of the output returned to the subjects.

As mentioned above, the elapsed time the user must wait from submission of his program to the return of his output is a measure of the computer system's feedback delay. The minimum feedback time available to users of the conventional computer system was six hours during the day and ten hours at night (overnight). Two submissions of computer runs

of significance. The standard statistical test used was the Mann-Whitney U test (Siegel, 1956). Other tests included the Chi-Square (ibid.) and the Kolmogorov-Smirnov (ibid.)

4 The computer system exhibiting those features which are characteristic of time-sharing would normally be labeled the 'experimental' system and the system exhibiting traditional characteristics as the 'control' system.

were scheduled each day for these users.⁵ For the users of the time-sharing system, the minimum feedback time was almost negligible, with first output returned much less than one minute after program submission. Complete output was returned in time periods ranging from one to six minutes. The capability of the console typewriter to type the requested quantity of output determined this amount of time.

If instead of viewing the computer system's feedback time, we focus on the user and his feedback time,⁶ we find the use of the traditional computer system results in a user feedback delay of several hours between the return of output and submission of his next set of computer input.⁷ For the users of the time-shared computer system, the time between receipt of output and submission of another set of computer input (while at the console) averaged between

5 These feedback times were selected as a compromise between the best and the worst service typically available with batch-processing computer systems. In most facilities, it would be unusual to be able to receive output and submit programs more than three or four times a day. Similarly, it would be unusual not to be able to do this at least once a day.

6 This might be a more relevant consideration if the user is problem-solving with ill-defined tasks. Unfortunately, there appears to be little attention paid to this requirement in the design of computer systems.

7 This was not an arbitrarily imposed course or computer system restriction -- users could submit their next set of input almost immediately after receiving their output. However, this did not appear to be advantageous to the problem-solving process.

five and ten minutes. The duration between sessions at the time-sharing console did not appear to be significantly different from that for the batch-processing system users.

The most important 'qualitative difference' between the two programming languages used in the Management Information Systems course can best be described by discussing differences observed during execution of a user's program. While both FORTRAN II and FORGO programming languages provided approximately forty-five to fifty-five source language error messages, FORTRAN II provided about two dozen error messages during execution, most of which referred to undefined computations. Since this language had been compiled and the error checking phase occurred only after the error took place, an error could halt the computer with no indication of the source of the problem. Less serious errors resulted in the user being notified of the type of error, but did nothing to help him identify the variable which had been affected or the location of the error in the user's source program.

The FORGO system operated differently. It not only provided a substantially greater number and variety of error messages during execution of the user's program (over ninety messages), but it also checked for potential errors before an illegal computation was allowed to occur and, if it found these conditions, notified the user about the type of problem, its cause, the variables involved, and the location of the error in the source

program.⁸ As a result of these differences in program execution, FORGO users rarely appeared to be confused about the location and source of their errors -- an advantage that did not accrue to the users of the FORTRAN II programming system.

Validation and Application of the Methodology

The validation, or testing, of the methodology and the evaluation of user behavior under the particular application on the computer system used are, of necessity, intertwined in this research. The validation process requires that an evaluation be conducted; the evaluation requires a valid methodology. Rather than attempt to resolve this logical conflict, we shall conditionally accept the methodology as valid and use it to evaluate the experimental setting. If its use appears correct, i.e., the evaluation seems to be reasonable, use of the methodology will continue, and it will be advanced as such, with these evaluations as supporting evidence. If the use of this methodology appears incorrect or unreasonable, both the methodology and the evaluation conducted must be rejected.

⁸ In addition, if the user still could not locate his problem, a very powerful and useful feature was available which allowed the user to trace the flow of his program and obtain the value of each calculation.

Computer System Cost

As presented in Chapter III, the total cost of computer system usage, in terms of simple algebraic constructs, is:

$$C = R_m \times V_m + R_c \times V_c$$

Where: C is the total 'direct' cost to produce a problem solution.

R_m is the amount of the man's resources (or time) expended.

V_m is the value of each unit (hour) of a man's resources expended.

R_c is the amount of computer system resources expended.

and: V_c is the value of each unit of the computer system's resources expended.

The unconstrained expenditure of the man's resources and the computer system's resources⁹ were experimentally determined independent of the level of Performance or the Speed of Problem Solution. The mean man-time expended by the users of the time-shared computer system was 15.5 hours, but the users of the conventional computer system, it was 19.3 hours. This difference is significant at the P<0.05 level.¹⁰

9 The subjects had an unlimited amount of computer resources available to them -- they allocated their own time to the task.

10 These figures were obtained by user responses to two types of questionnaires -- one completed after each interaction with the computer, and the other after the end of the experimentation. See Appendix B for these questionnaires.

The amount of computer resources (time) used by members of the two groups is very significantly different. An average of 1.25 minutes (0.0208 hours) were used by subjects assigned to the traditional computer system and 7.13 minutes (0.119 hours) by subjects assigned to the time-shared computer system.¹¹

Setting the cost equations for the two systems equal and substituting these experimentally determined values yields:

$$3.8 \times V_m = 7.13 \times (\underline{a} \times V_c) - 1.25 \times V_c$$

or: $V_m = V_c \times ([0.0313 \times \underline{a}] - 0.0055)$

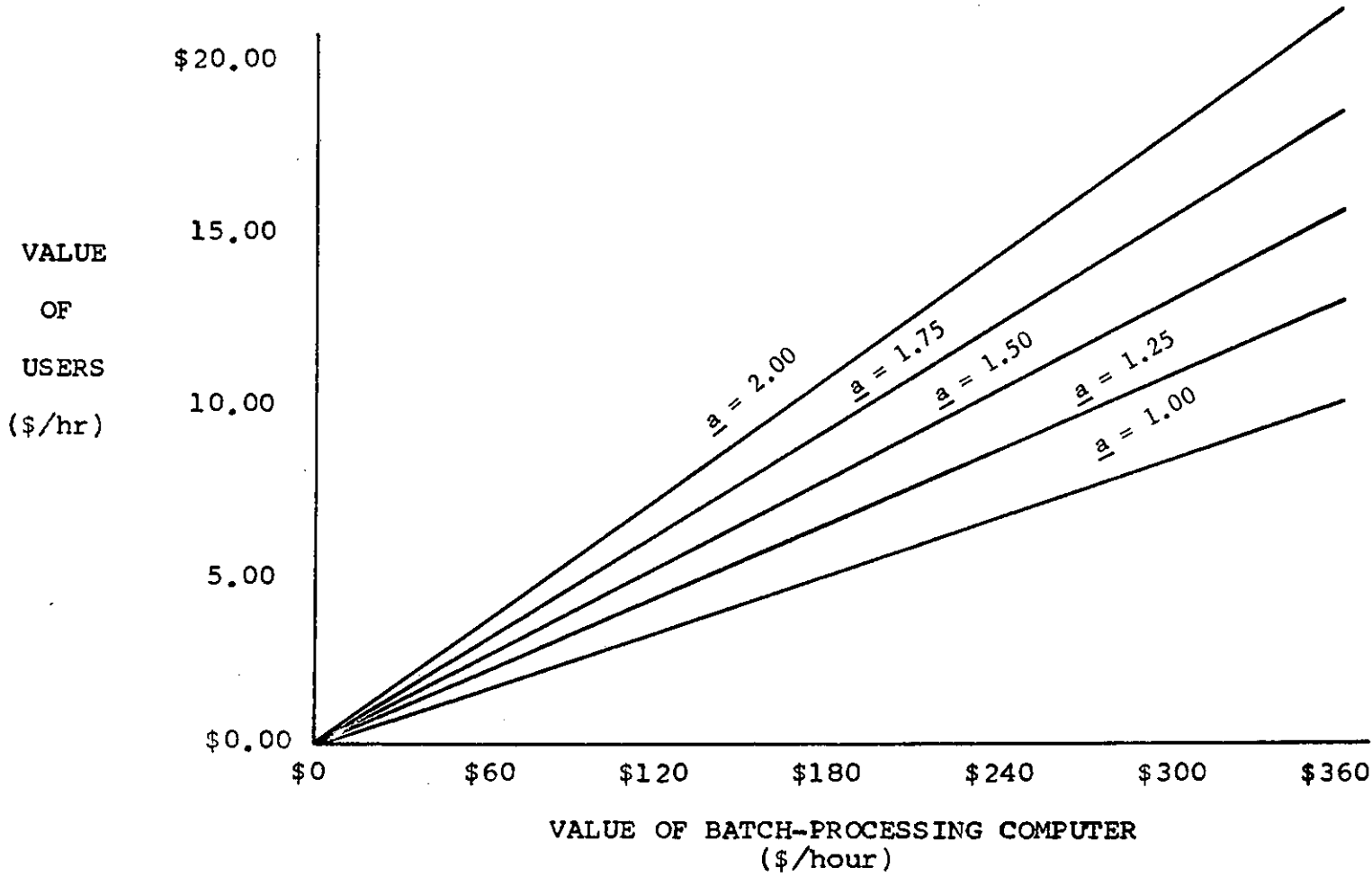
Therefore, if the value of an hour of the user's time is greater than the product of $([0.0313 \times \underline{a}] - 0.0055)$ and the per hour value of the traditional computer system, economic justification would exist for use of the time-sharing system (given equal levels of 'performance'); or, alternatively, if the value of the man's time was less (and 'performance' levels were equal), the economic justification would lay with the traditional computer system.

The curves representing the relationship between V_m , V_c , and \underline{a} -- with \underline{a} ranging from 1.00 to 2.00 in increments of 0.25 -- are presented in Figure 5. The hourly value of the user is recorded on the vertical axis and

¹¹ These numbers reflect the amount of time charged by the computer system for its use.

FIGURE 5

BREAKEVEN VALUE OF USER AS A
FUNCTION OF COST OF COMPUTER SYSTEMS



the per hour value of the traditional computer system is presented on the horizontal axis. Using values for purposes of demonstration, based on the computer system actually used in this research, a traditional computer system value of \$360 per hour and a time-shared computer system at \$540 per hour (\underline{a} equals 1.50), would result in a break-even value of \$14.90 per hour for the user. If the value of the time-shared computer system was only twenty-five percent higher than that of the traditional computer system (\underline{a} equals 1.25), this breakeven value would drop to \$12.15 per hour.

Assuming an \underline{a} of 1.50, the total cost of using either system for equal cost (the breakeven point) would be:

$$\begin{aligned} C_t &= R_m \times V_m + R_c \times V_c \\ \text{or:} &= 15.5 \times 14.90 + 0.119 \times 540. \\ &= 231.00 + 64.30 = 295.30 \end{aligned}$$

Approximately twenty-one percent of the total cost of solving this problem using the time-shared computer system (at the breakeven value) was charged to the computer. With use of the traditional computer system, this amounted to only two and one-half percent of the total cost.

Performance

Two measures of each subject's performance on the Industrial Dynamics task were available: (1) the level of output produced by his computer model; and (2) an

evaluation of the methods used to obtain the problem solution, independent of the first measure.

Output Level

The average 'model output' produced by the users of the traditional computer system was \$1215. For the users of the time-shared computer system the corresponding output was \$1404. ($P < 0.002$; Mann-Whitney $U = 218$; $n = 29, 29$).

It is always possible that manipulation of a variable other than those considered -- in this case, computer system characteristics and user behavior -- caused the differential performance. The most reasonable of the possible alternatives will be investigated: First, it is possible that a larger proportion of time-sharing users had sufficient time to complete the assignment, and, thus, this performance difference was caused solely by this 'sufficiency of time! Second, it is possible that the number of interactions with the computer system, independent of the computer system itself, governed the level of performance, i.e., each interaction added to performance. Third, it is possible that the faster feedback of output and higher rate of interaction resulted in different user behavior patterns which resulted, in turn, in the higher level of performance as hypothesized.

The first of these alternative explanations was investigated by separating those subjects who 'had sufficient time' to complete the assignment from those who did not and analyzing differences in the level of performance.

The resulting data is shown in Table 3.

TABLE 3¹²

RELATIONSHIP BETWEEN PERFORMANCE AND
SUFFICIENCY OF TIME TO COMPLETE ASSIGNMENT

| Computer System | <u>Users' Responses</u> | | |
|------------------|-------------------------|-----------------------|--------------------------------|
| | Total | "Had Sufficient Time" | "Did Not Have Sufficient Time" |
| Time-Sharing | \$1404 | \$1475 | \$1350 |
| Batch-Processing | 1215 | 1330 | 1184 |
| DIFFERENCE | \$ 189 | \$ 145 | \$ 166 |
| P[1-tail] < | 0.002 | 0.12 | 0.12 |
| Sample Sizes * | 29, 29 | 16, 10 | 9, 14 |

* The first of these two numbers refers to the number of subjects assigned to the time-sharing system responding.

This analysis demonstrates that although the difference between the group means is approximately maintained, this difference is no longer significant when the sample size is reduced. It does appear that this lack of significance resulted not from any difference caused by the 'sufficiency of time', but rather by the smaller sample sizes that resulted from the partitioning of the data.

The second of the possible explanations was investigated through correlation of the level of computer output with several measures of computer usage. Results of the analysis are presented in Table 4 and indicate a sig-

12 The total sample is not represented because some subjects did not respond to this question.

nificant relationship between several measures of computer usage and performance.

TABLE 4

CORRELATION BETWEEN PERFORMANCE AND COMPUTER USAGE

| <u>Computer Usage Measure</u> | <u>Correlation for:</u> | | | |
|--|-------------------------|------------------|---------------------|------------------|
| | <u>Batch-Processing</u> | | <u>Time-Sharing</u> | |
| | <u>Tau*</u> | <u>P[1-tail]</u> | <u>Tau</u> | <u>P[1-tail]</u> |
| Number of computer interactions | 0.129 | 0.120 | 0.395 | 0.003 |
| Number of error-free computer interactions | 0.240 | 0.068 | 0.360 | 0.006 |
| Number of productive computer interactions | 0.314 | 0.025 | 0.314 | 0.011 |
| Number of sessions with the computer | 0.129 | 0.130 | 0.488 | 0.001 |

* Kendall-Tau Correlation Coefficient (Siegel, 1956).

Although a basis does exist for assuming that performance is related to computer usage, it appears that 'computer usage' must be carefully defined. For batch-processing usage, it appears that the number of computer runs which resulted in usable output is most highly correlated with performance. For the time-sharing users, it would appear that the number of sessions with the computer console is most highly correlated. As is evident from Table 4, these relationships do not fully explain the differential levels of performance -- even within the time-sharing or batch-processing groups.

Report Evaluation

Evaluation of the strategies used to obtain the problem solution was achieved by defining four classifications on which to measure the subjects' written reports: (1) the students' understanding of the dynamic interactions within the model; (2) the extent to which the strategy devised, recognized and used the observed model dynamics; (3) the flexibility of the strategy to adapt to changing conditions; and (4) an evaluation of the students' perceptiveness and understanding of the problem. All of the above were designed to be measured independently of the results actually produced by the computer model.¹³

There was no significant difference between the two groups of subjects when the total grades, the sum of the grades for these four categories, were compared (Table 5). The same lack of significant differences were found after analyzing the grades assigned for the first three categories above. However, analysis of "the students' perceptiveness and understanding of the problem" demonstrated significantly higher grades for the users of the time-sharing system. (P[2-tail]<0.04).

13 In practice, the instructor in the Industrial Dynamics course required the portion of the users' output which gave a listing of the model -- use of these listings identified the computer system to which the subjects had been assigned.

TABLE 5

ANALYSIS OF SUBJECTS' WRITTEN REPORTS

| <u>Evaluation Categories</u> | <u>"D"*</u> | <u>λ^2</u> | <u>P[2-tail]</u> |
|---|-------------|-------------------------------|------------------|
| Subjects' understanding of computer model's dynamics | .16 | 1.25 | >0.50 |
| Strategy's use of computer model's dynamics | .23 | 2.42 | >0.30 |
| The flexibility of the strategy developed | .12 | .72 | >0.70 |
| Subjects' perceptiveness and understanding of the problem | .35 | 6.38 | <0.04** |

* "D" is the statistic for the Kolmogorov-Smirnov test of distributional differences (Siegel, 1956).

** The subjects assigned to use the time-shared computer system received higher grades on this measure.

Speed of Problem Solution

As discussed in Chapter III, the Speed of Problem Solution depends greatly upon definition of the two relevant measurement points -- the initiation and the completion of the task. The operational definition of the initiation of the task was the date effort was first expended on the task. For completion, the data of the last expenditure of effort was used. Analysis of the data indicated: (1) the date of the first expenditure of effort occurred concurrently for both groups of users; and (2) the date of the final expenditure of effort was typically determined by the deadline imposed -- not by the completion of the task. Substitution of the date of the first

use of the computer system provided substantially similar results. As would be expected, the total elapsed time from the first to the last computer interaction was equal for both groups of subjects.

Even though the completion date was the same for both groups in this experimental setting, it is possible that measurement of the elapsed time, had the users been able to work until completion of the task, would have shown that the availability and use of time-sharing resulted in a significantly faster Speed of Problem Solution. The users' responses to the question:

Have you had sufficient time to complete your analysis of the . . . case?

indicated that almost half of the total subject population did not consider themselves finished. If use of the time-sharing system actually resulted in a faster Speed of Problem Solution (shorter elapsed time), and both groups of subjects started the assignment at the same time (as they did in this experiment), then this hypothesis would expect a higher proportion of time-sharing users to report having had sufficient time to complete the assignment. Of the forty-nine subject responses (see Table 6), a significantly higher proportion of time-sharing users reported having had sufficient time. ($P < 0.06$; Chi-Square = 2.57)

The first two questions were used to verify the effectiveness of the experimental manipulations. A subject assigned to use the time-sharing computer system would be expected to indicate a significantly greater change in his experience on the time-sharing system -- the system he used -- than the batch-processing system -- which he did not use. If these expectations were not supported, the experimental manipulations would be open to question.¹⁵

Analysis of these 'change scores' demonstrates support for the hypotheses. For the users assigned to the batch-processing system, a significantly greater increase in experience level using batch-processing than time-sharing occurred. ($P < 0.001$: Mann-Whitney $U = 49$; $n = 17, 14$). Similar results were obtained for users assigned to the time-shared computer system. ($P < 0.001$: Mann-Whitney $U = 130$; $n = 22, 24$).

Analysis of the change scores for the time-sharing users' and the batch-processing users' responses to their "experience in writing DYNAMO programs" indicated a somewhat significantly greater increase in the relative responses by the users of the time-sharing system than by the users of the batch-processing computer system. ($P < 0.08$: Mann-Whitney $U = 202$; $n = 22, 24$).

same question administered after the experimental task. It allowed the experimenter to measure changes resulting from an experimental manipulation and reduce external bias.

¹⁵ The complement of this analysis, substitution of the batch-processing system for the time-sharing system, must also be supported.

Analysis of the time-sharing users' and batch-processing users' change scores or "difference between differences" for their experience analyzing Industrial Dynamics problems' indicated no significant difference in the responses ($P[2\text{-tail}] > 0.62$; Mann-Whitney $U=242$; $n=22, 24$)

Users' Attitudes

The relevant attitudes were defined as those which could affect the users' behavior. Two major categories were constructed: those attitudes which dealt with the usefulness (or value) of the computer system; and those which dealt with the value of the output produced. The following questions were asked of all subjects involved in the Industrial Dynamics experimental task:

What is the value of the time-sharing system in helping you analyze Industrial Dynamics problems?

What is the value of the batch-processing system in helping you analyze Industrial Dynamics problems?

When the users' responses to the above questions for the assigned systems were compared -- i.e., "what is the value of (the computer system you used) in helping you analyze Industrial Dynamics problems?" -- no significant differences were found. ($P[2\text{-tail}] > 0.50$; Mann-Whitney $U=92$; $n=24, 9$)

The responses by the subjects assigned to the batch-processing computer system concerning the value of the

time-sharing system indicated a significant increase after the experimental task. ($P < 0.02$; Mann-Whitney $U = 206$; $n = 23, 28$) The opposite type of change is indicated by the subjects assigned to the time-sharing system, i.e., after the experimental task their responses indicated they thought the batch-processing system was less valuable than they did before the experiment. ($P < 0.07$; Mann-Whitney $U = 59$; $n = 16, 11$)

After the experimental task, both groups of users were asked:

How useful was the computer system you used (batch-processing or time-sharing) in helping you solve the assignment?

How useful would the other computer system have been in helping you solve the assignment?

The responses indicated that both groups of subjects considered the time-shared computer system to be much more useful than the batch-processing system. ($P < 0.0001$)

In response to:

How satisfied are you with your results?

the users of the time-sharing computer system indicated a significantly higher level of satisfaction with their final output than did the users of the traditional computer system. ($P < 0.005$; Mann-Whitney $U = 160$; $n = 23, 25$)

Management Information Systems Analysis

The Management Information Systems experimental setting, in addition to providing further testing and validation of the methodology, was designed as an investigation of potential effects of qualitatively different types of feedback upon the users. To facilitate this research, both the FORTRAN II and FORGO programming languages were made available for use by the experimental subjects.¹⁶ The results presented below, although somewhat less detailed than those presented for the Industrial Dynamics experiment, are not inconsistent with the previously presented findings.

Computer System Cost

One of the two components of Computer System Cost, the amount of user time expended to complete the task, was somewhat lower ($P < 0.10$; Mann-Whitney $U=69$; $n=12,16$) with use of the 'qualitatively better feedback' programming system (FORGO). The mean amount of time expended by users of this experimental programming language was sixty hours versus seventy-three hours for the control language (FORTRAN). However, the amount of computer resources expended did not appear to differ -- the average number of computer interactions for both sets of users was approximately twenty-five. Although no accurate means were available

¹⁶ The qualitative differences introduced by these programming languages and the justification for this design were presented in Chapter IV.

for determining the amount of the computer's resources expended, an examination of the operational characteristics of both programming languages provided some valuable insight. The FORTRAN II programming language compiled (translated) the users' entire program to the language used by the computer before beginning to execute the users' program. The FORGO programming language, on the other hand, translated each program source statement only when it was necessary in order to execute it. Although each method had its advantages -- FORTRAN II executed rapidly while FORGO began execution almost immediately -- the high time cost to compile a program is a disadvantage if the amount of time spent in execution was small. A short amount of execution time was typical during the process of debugging computer programs.

Performance

The subjects' output was evaluated along two dimensions: the correctness of the computer output, and the perceptiveness of the user as evidenced by the report accompanying the output. The first evaluation was obtained by measuring the correctness of the users' output as compared with optimal output. The second was obtained from the instructor's evaluation of the written report. No significant differences were observed on either measure.

Speed of Problem Solution

Four significant dates during the problem-solution process were recorded: (1) when work was begun; (2) the commencement of programming; (3) first use of the computer system; and (4) formal completion of the assignment. As expected with the use of the same programming source language by groups with similar population characteristics, there was no significant difference between the experimental and control groups on the first three measures. The fourth measure, the completion date, was the only one of the four which reasonably could have been affected by use of the programming language. It had been hypothesized that those subjects with the 'better' system feedback would require less elapsed time to complete the assignment and would thus turn it in sooner. However, the date the assignment was handed in was, for most subjects, governed by the deadline for completing the assignment. This may not necessarily have coincided with the date the subjects would have finished.

Another method of determining the Speed of Problem Solution, or the degree of subject completion at the imposed deadline, was attempted by asking the subjects after the assignment:

Have you had sufficient time to complete the programming assignment?

The difference between the responses for the experimental

and the control groups did not differ significantly.

($P[2\text{-tail}] > 0.25$; Mann-Whitney $U=71$; $n=12,16$)

Users' Attitudes

To the inquiry:

How useful was the programming system you used (FORGO or FORTRAN II) in helping you program and debug the problem?

the subjects assigned to the experimental system (FORGO) evaluated their programming system as more useful than did the users of the control system ($P < 0.05$; Mann-Whitney $U=65$; $n=12,17$).

The subjects' response to:

How satisfied are you with your final results?

indicated a higher level of satisfaction for users of the experimental system ($P < 0.02$; Mann-Whitney $U=56$; $n=12,17$)

User Behavior

Data other than those resulting from the application of the methodology to the two experimental computer systems are available for further investigation into the behavior of computer system users. Analysis of these measures can provide the insight necessary for the effective design of future computer systems in line with user behavior patterns. The areas investigated can be described as: the relationship between decision-making strategy and performance; (2) the effect of inter and intra console session interactions (time-shared) on performance; and (3) the rela-

tionship between the number of interactions with the computer system and performance.

Decision Making Strategy and Performance

After each interaction with the computer system, members of both groups of users working on the Industrial Dynamics task were required to complete a questionnaire related to their purpose in initiating the computer interaction and the output (including their evaluation of the output) of the interaction. One of these questions related to the purpose of making the [then] current changes in the computer model. The four answers supplied were:¹⁷

Try a totally new decision rule

Introduce other factors into existing decision rule

Re-run to try different constants

Correct previously undetected program errors

All responses for the two groups resulted in the distribution of data displayed in Figure 6a. None of the differences are significant.

In his study of decision-making and job choice, Soelberg found that people adopt problem-solving strategies such that they search in the immediate vicinity of a strategy within a problem-solving session and switch strategies

¹⁷ A fifth category was labeled 'Other' Its use was limited however, and the majority of these few responses could have been mapped into one of the four categories above.

FIGURE 6A*

PURPOSE GIVEN FOR COMPUTER INTERACTIONS
(TIME-SHARING VS. BATCH-PROCESSING)

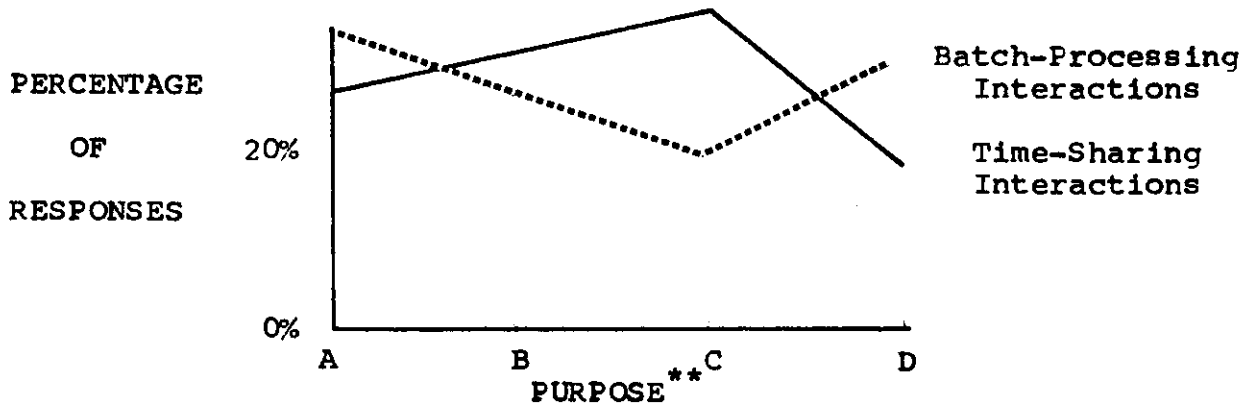
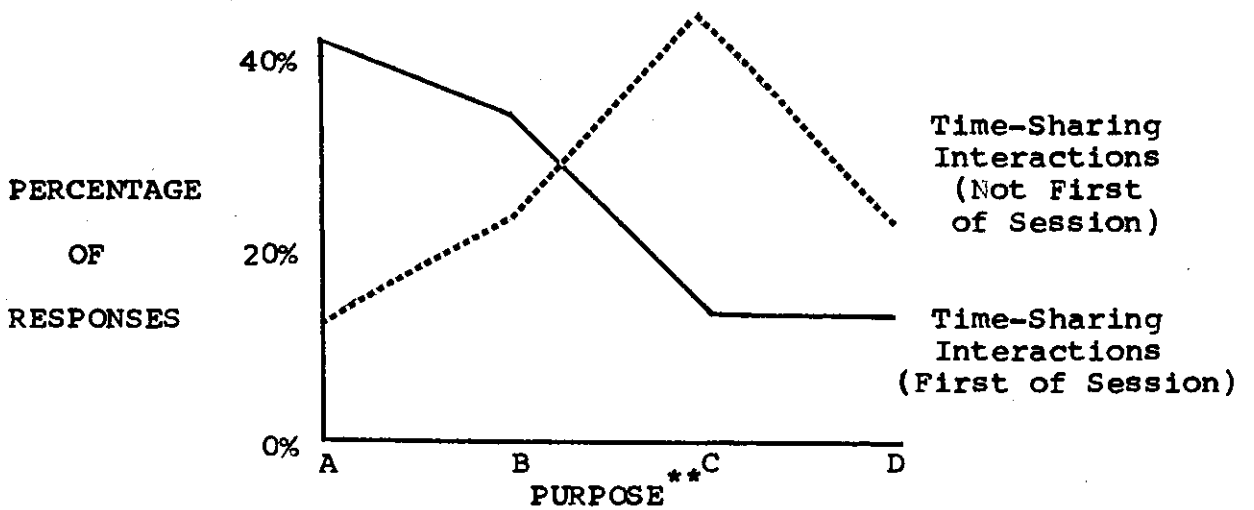


FIGURE 6B

PURPOSE GIVEN FOR COMPUTER INTERACTIONS
(INTRA VS. INTER CONSOLE SESSIONS)



* This may be somewhat biased as a result of differential rates of completing questionnaires by time-sharing and batch-processing users. The latter group completed 91% of their questionnaires -- the former only 44%. Analysis indicated that computer interactions involving simple syntactic errors were the primary contributors to this low percentage.

- ** The categories of responses supplied were:
- A Try a totally new decision rule
 - B Introduce other factors into existing decision rule
 - C Re-run to try different constants
 - D Correct previously undetected program errors

between sessions. (Soelber, 1967) These findings resulted in an intensive investigation of the time-sharing users' reasons for making changes in their computer model (and thus another interaction with the computer). Analysis of their responses indicated a significant difference between their reasons for changes in the first effective interaction of a session and subsequent interactions. The first interaction of a session was for the primary purpose of making major changes in the decision rule of their computer model.¹⁸ Of the remaining interactions during the session however, only one-third had the making of these major changes in the decision rule as the primary purpose. Forty-four percent of these remaining interactions were for the purpose of manipulating constants.

Analysis of these differences between the first and subsequent interactions demonstrated these differences to be extremely significant. ($P < 0.0001$; Kolmogorov-Smirnov $D = 0.42$; $n = 75,125$). See Figure 6B.

Inter and Intra Session Performance

As a result of these findings with the purposes for computer interactions by time-sharing users, an investigation was initiated to determine if a similar relationship existed concerning the performance level. As with the investigation of decision-making strategy, the

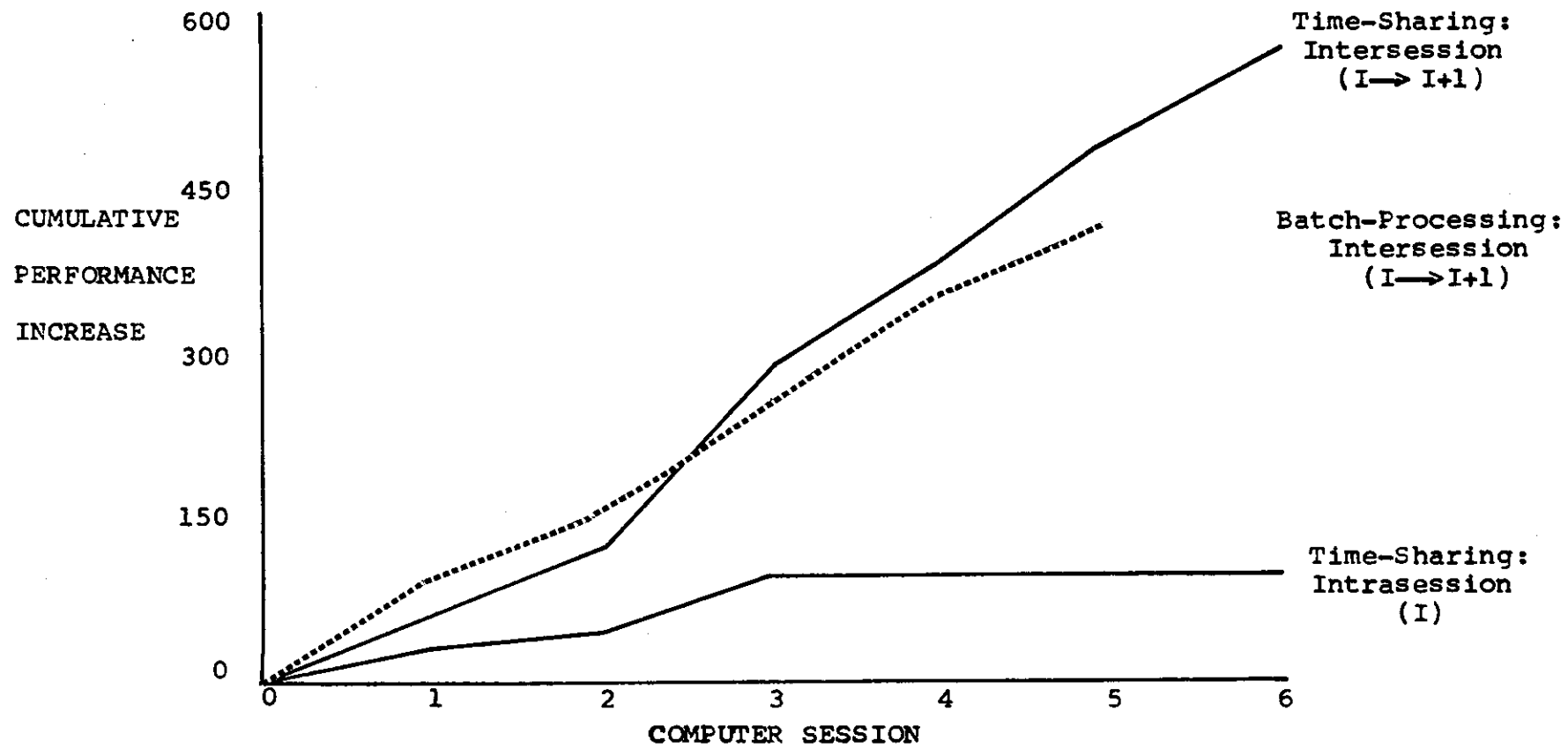
¹⁸ Approximately seventy-five percent of these first interactions had as their primary purpose either answers 'a' or 'b' above.

analysis considered the first effective interaction of a session with the time-shared computer independently from the remaining interactions of the session. The average increase in the level of performance for the first interaction was initially calculated in several ways: (1) the increase from the last interaction of a console session to the first of the next session; (2) the increase from the first interaction of a session to the first interaction of the next session less the increases of subsequent interactions during the session; and (3) the total increase in performance minus the increases for the second through the last interactions of a session. The first two methods were reused with only increases in performance level considered. The analysis indicated an average increase in performance for the first interaction of a session with the time-shared computer of between \$88 and \$129¹⁹ For interactions during that console session but subsequent to the first interaction, an average increase in performance of between \$24 and \$39 was observed. For the batch-processing system, the average increase in performance from one computer session to the next was approximately \$90.

The cumulative average performance increase for intra and inter time-sharing sessions is shown in Figure 7. Figure 7 also includes the comparable intersession measures for the batch-processing system.

¹⁹ This range is, of course, dependent upon which of the analysis methods was used.

FIGURE 7
RELATIVE PERFORMANCE INCREASES
BETWEEN AND WITHIN COMPUTER SESSIONS

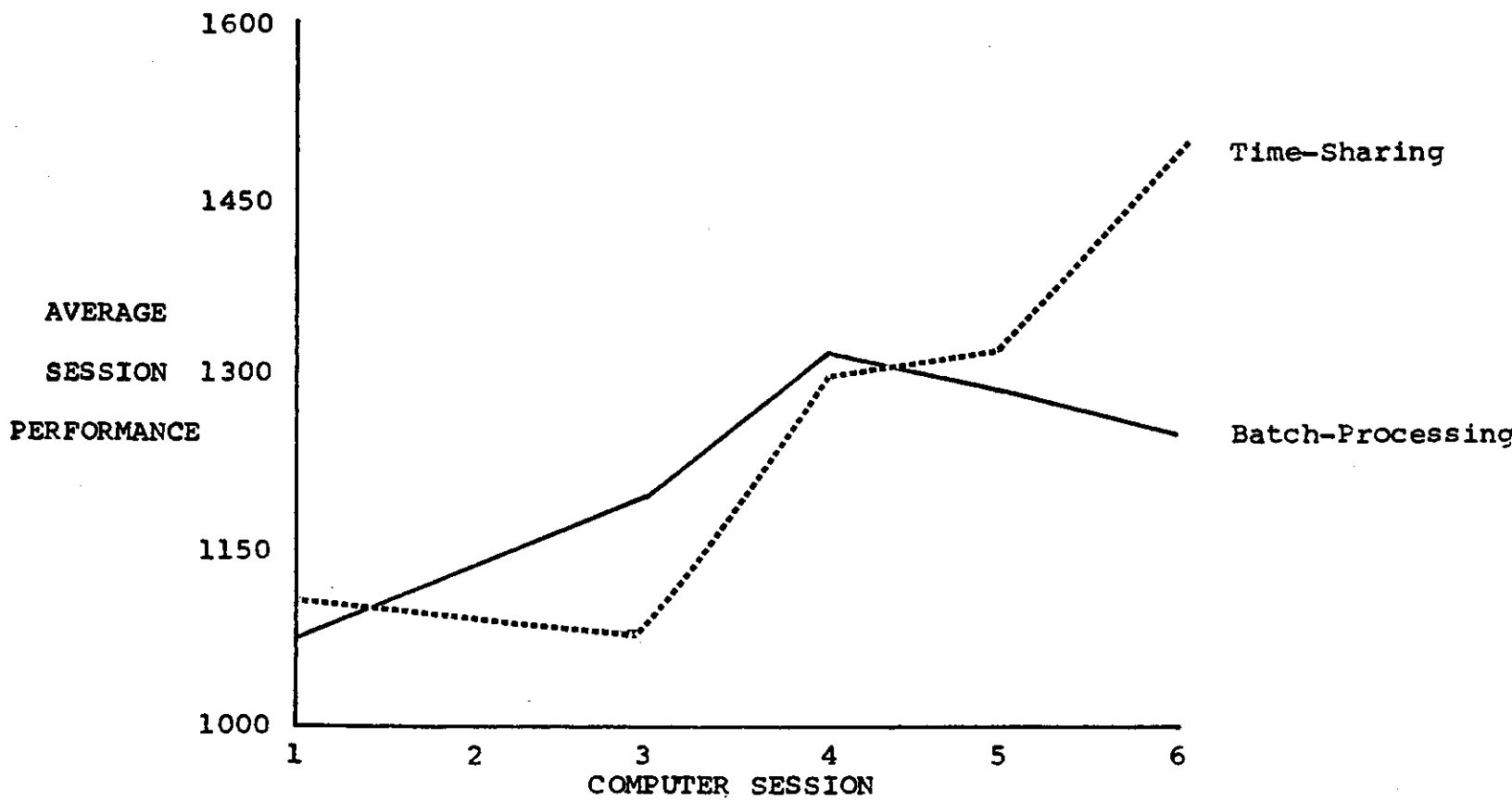


Number of Interactions and Performance

The subjects assigned to the batch-processing system interacted with the computer system an average of 5.8 times, the subjects assigned to the time-sharing system interacted 19.2 times. With 3.3 times as many interactions with the computer system, the average increase in the performance level of the users of the time-shared system was only 2.4 times as great as that of the batch-processing users. This level of performance, as a function of the number of interactions, is displayed in Figure 8. As another means of measuring performance, the 'computer session' was defined.²⁰ Analysis of the computer output for both groups of subjects indicated the number of computer sessions were approximately equal for the two groups with 4.8 computer sessions for the batch-processing users and 4.7 for the time-sharing users. The increase in the level of performance for the batch-processing users showed a fairly constant rate of increase until the fifth computer session, when it began to decrease. The performance level of the time-sharing users decreased slightly for the first three computer sessions. At that time, the slope changed drastically and the performance showed marked improvement.

²⁰ This is defined as a semi-continuous period during which the user interacts with the computer system at least once.

FIGURE 8
ANALYSIS OF PERFORMANCE
AS A FUNCTION OF COMPUTER SESSION



CHAPTER VI

Summary

The primary objective of this research was the development of a methodology with which to evaluate time-shared computer system usage. As part of the validation process, the methodology was used to evaluate two experimental applications. Three sets of conclusions will be presented in this summary, those relating to: the methodology; the evaluations using the methodology; and user behavior observed during experimentation.

Methodology

As a result of these evaluations, there appears to be sufficient evidence for the following conclusions concerning the methodology:

a) The summing of the costs of the scarce resources in the computer system, those of the computer and the man, adequately measure the cost of using the computer system. The cost of achieving a given level of performance, learning, or speed of problem solving can be calculated by measuring the amount of expenditure of each resource required to reach the desired levels or speed.

b) An evaluation of the output produced through the use of the computer system appears to provide one measure of performance. An evaluation of the users' analysis

techniques for obtaining these results, independent of this output, provides a second measure.

c) The multiple-task demands typically imposed on computer system users complicate the process of measuring the Speed of Problem Solving. Although the total elapsed time would appear to be an appropriate measure of the Speed of Problem Solving, there are problems of both operationally defining it and implementing any definition when the user works on more than one task concurrently. In practice, the tendency of users to finish a task only at the "deadline" makes measures of elapsed time meaningless. The concept of "sufficiency of time" eliminates most of these problems, but introduces the possible problem of bias through the use of subjective measuring techniques.

d) The use of subjects' estimates of their achievement level may have value, but possibly lack the reliability and validity of more objective instruments, e.g., standard achievement tests. These tests were not used, however, so the atmosphere of the natural setting could be preserved.

e) Users' attitudes toward both the usefulness of a computer system and the value of the output produced through its use appear to act as surrogates for the harder-to-measure, "user behavior" which may be influential in determining the quality and quantity of computer system usage.

Evaluation Results

As a result of using the problem-solving experimental settings, the following general conclusions appear reasonable where the independent variables are the speed of feedback of output and rate of interaction with the computer system:

a) The total cost of time-sharing and batch-processing usage do not appear to differ appreciably. However, there is a basis on which to forecast higher computer cost and lower man cost with time-sharing usage.

b) Use of the time-sharing system resulted in a higher level of objective performance than did use of the batch-processing system. At the same time, the time-sharing users' "perception and understanding of the problem" was evaluated as demonstrating a significantly higher performance level.

c) By re-defining the Speed of Problem Solution as the "sufficiency of time to complete the assignment" instead of the amount of elapsed time required, it appears that a significantly higher proportion of the time-sharing users than batch-processing users considered that they had finished the assignment.

d) The time-sharing users evidenced a greater change in experience using the programming language than did the batch-processing users. No comparable difference was observed in the users' experience analyzing problems of the type presented.

e) More favorable attitudes toward the use of time-shared computer systems and the results produced through the use of the computer system were evidenced.

As a result of using the Management Information Systems experimental setting, the following general conclusions appear reasonable where the independent variable is the "quality" (or completeness) of the computer output.

a) The cost to use the "qualitatively better" computer system does not appear to differ appreciably from the cost of the other computer system. There is no evidence to indicate that use of this "qualitatively better" programming system will result in fewer interactions between the user and the computer system. There is, however, some basis for forecasting that "qualitatively better" computer systems will result in a smaller number of man hours required for a task solution.

b) The users of the "higher quality" programming system indicated more favorable attitudes toward both their programming system and the results produced through its use than did the users of the other programming system.

c) There was no measurable difference in the level of performance attained or the Speed of Problem Solution with use of either programming system.

User Behavior

During the validation process, the following results concerning user behavior were obtained:

a) The users of the time-sharing system interacted with their computer system more than three times as often as did the batch-processing users.

b) There was no significant difference between the reasons advanced by time-sharing or batch-processing users for initiating computer interactions. A significant difference was observed, however, between the time-sharing users' reasons for initiating the first and subsequent interactions during a session with the computer console -- a significantly higher proportion of these initial interactions were to make major modifications in the decision-rules while subsequent interactions were to make minor adjustments within these decision-rules.

c) These differences in the users' reasons for initiating time-shared computer interactions are paralleled by differential user performance. The average increase in performance for the first interaction of a session was more than three times as great as for subsequent interactions.

d) There was a strong relationship between a batch-processing users' performance level and the number of computer interactions which produced usable output. For the time-sharing users, the correlation between performance and the number of sessions with the time-shared computer

console is strongest.

Generalizability

One question of immediate relevance is the generalizability of the results of this research. This question must consider the two distinct portions of this research separately: first, the generalizability of the methodology for use in evaluating other forms of computer system usage; and second, the generalizability of the specific results of the two evaluations conducted. The answer to the first of these questions depends upon both the evaluation functions presented and the operational definitions for these evaluation functions. In response to the second question, these results are generalizable to other applications or systems only to the extent that the computer systems, the experimental settings, and the subjects are generalizable.

The methodology was conceived to be independent of applications, computer systems, or users. Its implementation has concentrated on first defining the categories for evaluation -- cost, performance, speed, learning, and attitude -- relevant to computer system evaluation and then developing operational definitions for measurement.

It is evident that several of the evaluation functions will require further development to achieve a reasonable measure of general applicability. For example, the evaluation function for Computer System Cost assumes that time-sharing usage should be based on the amount of cen-

tral processing unit (CPU) time and the total cost of the hardware. Although this method might be acceptable for current computer systems, it is probably not acceptable for truly interactive computer systems. A second example of the further work required is the implementation of the Learning evaluation function. Simply questioning subjects concerning their level of experience is not as valid a method as using a test which measures their achievement level.¹

It would be difficult to relate these specific research findings to other settings until the following questions are answered:

What characteristics will time-shared computer systems have?

What types of applications will use such a system?

What form will the user population take?

Although predictions exist concerning the answers to these questions, it is beyond the scope of this research to evaluate them. Several issues concerning each of these areas will be briefly discussed however.

Both the responsiveness and flexibility of the time-shared computer system used in this research do not appear to be inconsistent with the design of second generation time-sharing systems. One major change seems apparent

¹ It should be realized that the method used was chosen to minimize the undesired effects which may accompany the alternate form of testing.

however -- the typewriter consoles used in the Industrial Dynamics research will probably be replaced by visual display consoles which will, as a minimum, provide a much faster speed of display than did the consoles used in this research.²

Time-shared computer systems will be used for three broad classes of applications; problem-solving, programming, and computing. The Industrial Dynamics application was chosen to be representative of the first two categories, with primary emphasis on problem-solving. The Management Information Systems application made use of all three categories, but placed primary emphasis on the second. No attempt will be made to justify these applications as typical of any broad class of applications due to the difficulty of defining it.

Two questions concerning the user population are important:

Were the subjects too naive in their use of the computer system?

How representative were these subjects of a population who might use this application?

Although we have no adequate measure of the "computer sophistication" of either set of subjects, the Industrial Dynamics users frequent use of the DYNAMO language for

² The "better quality" of feedback forecast for time-sharing systems was not available in the Industrial Dynamics research setting but was available in the Management Information Systems setting.

several months preceding the experimentation should have provided sufficient training. A majority of the Management Information Systems experimental subjects had been involved with computer programming prior to the experiment.

Seventy percent of the subjects in the Industrial Dynamics experiment were students in the management school at M.I.T. -- the remaining were graduate students in other departments. With the exception of a lack of experience in management decision-making, and possibly a higher intellectual level, there does not appear to be any basis on which to separate them from any definable population of relevant computer users.

One possible difference between the Management Information Systems subjects and a relevant population of managers -- in addition to a lack of managerial experience and a possible higher intellectual level -- may be the ability to program a computer.³

Transferability of Evaluation Results

The transferability of the specific results of this evaluation is a function of the generalizability of those factors mentioned above. However, there does appear to be some general applicability to computer system usage relatively independent of the experimental setting. That

³ When compared with a decision-maker, the subject's ability stands out. If the subject were to be compared with a full-time computer programmer, his ability would be far below average.

which appears to result from the faster feedback of output and higher rate of interaction or "higher quality" of output are discussed below.

Computer System Costs

There appears to be no verification that time-sharing usage will cost more (or less) than usage of more traditional computer systems. It does appear, however, that both faster feedback of output and a "better quality" of output independently reduce the amount of man-time required to attain a given level of performance. Although the interactive effect of both factors has not been studied, it would not seem unreasonable to expect similar results under such circumstances.

There appears to be no basis for expecting a difference in the amount of computer resources expended as a result of a "better quality" of output. Under the faster feedback of output conditions, an increased expenditure of computer resources was accompanied by an increase in the level of performance.

Performance

The analysis provided no basis on which to predict that so-called "better output" will result in a higher level of performance. It appears that the users of a computer system which provides faster feedback of output and an unlimited amount of computer resources will interact more frequently with the computer system than the user

with slower feedback of output and that this more frequent interaction somehow may be related to problem-solving performance.

Speed of Problem Solving

It is apparent that any computer system with a faster feedback of output and a higher rate of interaction will allow a faster speed of problem solving. In practice, these features did appear to result in a higher proportion of time-sharing users who "were finished" at the deadline -- or, in effect, had a faster Speed of Problem Solving.

Users' Attitudes

It appears indisputable that any computer system with faster feedback, greater ease of access, higher rates of interaction, or higher qualities of feedback will be received more favorably than will computer systems without these features.

The Role of Feedback Delays

The feedback mechanisms of presently designed time-shared computer systems work as follows: the user requests service from the computer; the computer system processes the requests quickly; and output is returned to the user. Immediately upon receipt of his output, the user is able to request additional service. From the computer system designer's standpoint, it appears that the only interesting feedback delay in this system is the one involved with returning output to the user.

While consideration of this feedback delay may allow optimal use of the computer system under a time-sharing mode, its sole consideration may not necessarily be efficient for the man in the man-computer system. Simon's view of the interactive system may be more appropriate (Simon, 1966, p.44):

In these systems the unit of interaction is almost always taken to be a sequence that begins with a message from the human component and ends with a response from the computer. Since, in a "conversation" between man and computer, there is symmetry between the two components, why not, instead, take as the unit of interaction a sequence that begins with a message from the computer and ends with the response from the human?...

Is either point of view, in fact, correct? Isn't the system really a closed feedback loop in which the human user proposes tasks to the computer and the computer to the human?

This would appear to argue for consideration of the appropriate user feedback times as well as computer feedback times. There are, of course, two periods during any interaction which are relevant to the user; the time from the request for service until output is returned, and the time from return of output to the request for service. The first of these has been discussed by Simon in terms of the efficient use of the man's resources and his ability to "time-share" himself between several tasks (Simon, ibid.). However, no attention has yet been paid to investigating efficient use of the man's resources from the return of output to the next request for service. The following

section will discuss this problem, based on these research findings, and will suggest a policy for more efficient use of the resources of both the user and the time-shared computer system.

During the period from receipt of output to the next request for service, the user must analyze the computer output, decide what changes, if any, should be made, operationally define these changes, implement them, and submit the next request for service. Between sessions with the time-shared computer system, the users studied in this research has approximately six to ten hours to accomplish the first three of these. Within sessions at the time-shared console, the users averaged less than ten minutes to complete, in some fashion, all five operations.

Although no definitive answers exist, it is certainly questionable whether the ten minutes between output and subsequent input was sufficient to adequately complete the necessary tasks. Several of this thesis's research findings indicate the time was not sufficient. The analysis of the users' purposes for initiating computer interactions indicated a much higher proportion of the initial interactions of a session (many hours after receiving computer output) were to make major changes in the decision-rule than for subsequent interactions (an average of ten minutes after receiving computer output). The primary purpose of these subsequent interactions were to make

minor adjustments to the existing decision-rules. Concurrently, the average increase in performance was substantially greater for the initial interaction than subsequent interactions of a session with the time-shared console. It appears that the purpose specified by the users would suggest a concentration on causal problems for the first interaction of a session and symptomatic problems thereafter.⁴

If the above accurately portrays the process of a man interacting with a computer system, it would appear to be mutually advantageous to perform a greater amount of analysis between the time of receipt of output and the submitting of the next request. A simple method to accomplish this might impose a minimum delay between the output and subsequent request. This could be accomplished by incorporating features into the computer system which refused to pay attention to the user for a length of time based on his experience and use of the system. Hopefully the user would, during this waiting period, utilize the time to search for a solution to the real cause of his problem, not just to the symptom of the problem. Although we would not attempt to specify this length of time without extensive research, it should be sufficiently long so the user will examine the logical design of his task carefully, but not so long that the user will turn to another

⁴ This is somewhat analogous to increasing the size of a format specification in a computer program because the magnitude of a number exceeded the specification. More appropriately, the programmer might search for the reason the number exceeded the specification.

task while waiting.

With such a feature, better use might be made of both the user's and the computer's resources. The user would spend more time searching for the causes of his problems, not the symptoms which might require even less of his time than under present time-shared computer systems. The computer system would benefit through decreased demand on its services by each user through the elimination of some valueless tasks.

Directions for Further Research

It is clear that this research has raised many questions. While some have already been discussed with a goal of further research, this section will attempt to bring together those relevant whether previously mentioned or not, specify some of the important questions raised, and to indicate those directions for further research not yet specified.

The evaluation functions presented here have been an initial attempt to provide operational definitions with which to evaluate computer system usage. Alternate means of measurement are needed for several of these functions while further research is needed into others. Measurement of the Speed of Problem Solving was achieved in this research after it was realized that the measurement of 'elapsed time' was not an adequate measure. The "sufficiency of time" concept used is, theoretically, more appropriate -- it is possible, however, that the users' responses may be influenced by factors other

than the Speed of Problem Solving.

Research is indicated to evaluate simplifying assumptions made to insure workable operational definitions of evaluation functions -- notably that of the Computer System Cost. For example, the total cost of using the computer was defined as the cost of the entire computer multiplied by the amount of CPU time charged. Although this has been the generally accepted method of charging, the use of on-line computer systems may necessitate an entirely new algorithm in the future.

The experimental settings used to test the methodology were not selected because they were typical of all relevant settings. Further testing under experimental conditions, which vary computer systems, applications, and subjects, will be required as part of the validation process.

The effect of varying computer system characteristics has been hypothesized and the two experiments conducted have studied the effect of differential speeds of feedback of output and qualities of this output. However, values of these variables other than what was thought to be "high" and "low" were not studied. In addition, other variables relating to console design, constraints on computer resources, user resources, or the amount of elapsed time available to provide a task solution, could not be systematically varied in this research. Further experimentation should be directed to an investigation of the

effect of changes in these variables upon user behavior and performance.

Finally, the suggestion of a strong relationship between the purpose of an interaction, the amount of time from the return of output to the next request for service, and the performance attained on the subsequent interaction, should be thoroughly investigated. Both laboratory and field experiments should study the effect of various amounts of time for this decision-making delay across various types of tasks. If the hypothesized relationship is supported, development of methods for introducing these delays into the interaction cycle should be implemented and evaluated.

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APPENDIX A

INDUSTRIAL DYNAMICS DATA
(TIME-SHARING SUBJECTS)

APPENDIX A

INDUSTRIAL DYNAMICS DATA
(TIME-SHARING SUBJECTS)

| Subject No. | #926-1 | #926-2 | #926-3 | #926-4 | #926-5 | #926-6 | #927-1 | #927-2 | #927-3a | #927-3b | #927-3c | #927-3d | |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|---------|---------|----|
| 01 | 3 | 3 | | | | 3 | 8 | Y | 480 | 60 | 20 | 0 | 20 |
| 03 | 1 | 1 | | | | 1 | 6 | n | | | | | |
| 05 | | | | | | | | | | | | | |
| 08 | | | | | | | | | | | | | |
| 09 | 1 | 1 | 1 | | | 1 | | Y | 60 | 75 | 25 | 0 | 0 |
| 11 | 2 | 2 | 2 | 4 | | 3 | 7 | n | | | | | |
| 13 | 1 | 1 | | | | 2 | 7 | Y | 60 | 100 | | | |
| 17 | 1 | 1 | | | | 3 | 9 | Y | 30 | 50 | 50 | | |
| 19 | 3 | 3 | | | | 3 | 6 | Y | 360 | 50 | 10 | | 40 |
| 22 | 3 | 1 | | | | 3 | 7 | n | | | | | |
| 66 | 1 | 2 | 1 | | | 1 | 9 | Y | 30 | 100 | | | |
| 26 | 1 | 2 | 1 | | | 1 | 8 | Y | 15 | 100 | | | |
| 29 | | 3 | 4 | 5 | | 1 | 9 | n | | | | | |
| 30 | 2 | 2 | 1 | | | 2 | 4 | n | | | | | |
| 31 | 2 | 3 | | | | 3 | 7 | Y | 90 | 50 | 30 | 10 | 10 |
| 34 | 1 | 1 | | | | 2 | 7 | n | | | | | |
| 36 | 2 | 3 | 1 | | | 3 | 7 | n | | | | | |
| 37 | 1 | 1 | 1 | | | 1 | | | | | | | |
| 40 | 3 | 2 | 1 | 4 | | 5 | 8 | n | | | | | |
| 41 | 3 | 3 | 1 | 5 | | 3 | 9 | n | | | | | |
| 42 | 3 | 2 | 6 | 4 | | 4 | 6 | | | | | | |
| 43 | 3 | 2 | 3 | 5 | | 3 | 6 | n | | | | | |
| 45 | 2 | 2 | 1 | 1 | | 2 | 2 | n | | | | | |
| 46 | 3 | 3 | 1 | 2 | | 3 | 6 | Y | 180 | 40 | 25 | 20 | 15 |
| 47 | 2 | 2 | | 1 | | 2 | 9 | n | 180 | 80 | 20 | | |
| 48 | 2 | 3 | | | | 2 | 6 | n | | | | | |
| 50 | 2 | 3 | | | | 5 | 5 | n | | | | | |
| 51 | 1 | 1 | 1 | | | 3 | 9 | n | | | | | |
| 53 | 5 | 6 | 1 | | | 5 | 7 | Y | 360 | 33 | 10 | | 25 |
| 56 | 3 | 3 | 1 | | | 3 | 3 | Y | 120 | 20 | 30 | 10 | 40 |
| 59 | 2 | 1 | 1 | | | 5 | 9 | Y | 180 | 30 | 30 | 20 | 20 |
| 63 | | | | | | | | | | | | | |
| 64 | 2 | 4 | 1 | 2 | | 4 | 8 | n | | | | | |

APPENDIX A

INDUSTRIAL DYNAMICS DATA
(TIME-SHARING SUBJECTS)

| Subject No. | #928-1 | #928-2a | #928-2b | #928-3 | #928-4 | #928-5 | #928-1* | #928-2* | #928-3* | #928-4* | #928-5* | #928-6* |
|-------------|--------|---------|---------|--------|--------|--------|---------|---------|---------|---------|---------|---------|
| 01 | n | | 6 | 9 | 8 | 5 | 7 | 7 | 1 | 1 | 7 | 9 |
| 03 | n | | 28 | 7 | 6 | 1 | 4 | 5 | 1 | 1 | 6 | 9 |
| 05 | | | | | | | | | | | | |
| 08 | | | | | | | | | | | | |
| 09 | | | | | | | | | | | | |
| 11 | y | 18 | | 1 | 6 | 5 | 1 | 3 | 1 | 3 | 5 | 7 |
| 13 | y | 18 | | 9 | 8 | 1 | 4 | 4 | 1 | 1 | 5 | 8 |
| 17 | y | 18 | | 9 | 7 | 3 | 5 | 3 | 1 | 1 | 6 | 7 |
| 19 | n | | 6 | 7 | 4 | 1 | 4 | 3 | 1 | | 3 | 8 |
| 22 | n | | 4 | 6 | 4 | 1 | 4 | 4 | 1 | | 4 | 6 |
| 66 | y | 18 | | 9 | 8 | 5 | 4 | 4 | 1 | 2 | 4 | 9 |
| 26 | n | | 4 | 9 | 5 | 5 | 4 | 4 | 1 | 5 | 3 | 9 |
| 29 | y | 21 | | 5 | 5 | 1 | 4 | 4 | 6 | 4 | 4 | 6 |
| 30 | n | | 1 | 8 | 7 | 4 | 5 | 4 | 1 | | 6 | 7 |
| 31 | y | 18 | | 8 | 7 | 5 | 5 | 5 | 1 | | 7 | 9 |
| 34 | y | 17 | | 9 | 8 | 4 | 5 | 3 | 1 | | 5 | 9 |
| 36 | n | | 4 | 9 | 6 | 3 | 3 | 4 | 1 | 3 | 4 | 7 |
| 37 | | | | | | | | | | | | |
| 40 | | | | | | | | | | | | |
| 41 | y | 17 | | 9 | 8 | 1 | 7 | 7 | 1 | 2 | 9 | 9 |
| 42 | | | | | | | | | | | | |
| 43 | y | 15 | | 9 | 9 | 4 | 7 | 4 | 4 | 3 | 5 | 8 |
| 45 | | | | | | | | | | | | |
| 46 | y | 16 | | 8 | 8 | 2 | 4 | 5 | 1 | 3 | 4 | 8 |
| 47 | | | | | | | | | | | | |
| 48 | y | 18 | | 9 | 7 | 5 | 7 | 7 | 1 | | 7 | 9 |
| 50 | y | 18 | | 9 | 7 | 1 | 5 | 5 | 1 | 1 | 8 | 8 |
| 51 | y | 15 | | 9 | 9 | 2 | 3 | 3 | 1 | 1 | 3 | 9 |
| 53 | n | | 2 | 6 | 6 | 7 | 6 | 6 | 1 | | 5 | 7 |
| 56 | y | 16 | | 8 | 7 | | 4 | 4 | 1 | | 4 | 7 |
| 59 | y | 18 | | 7 | 6 | 5 | 6 | 6 | 1 | | 7 | 7 |
| 63 | y | 18 | | 8 | 7 | 2 | 6 | 6 | 1 | 1 | 9 | 9 |
| 64 | n | | 28 | 8 | 6 | 2 | 5 | 5 | 1 | 3 | 7 | 9 |

* These refer to the second page of the questionnaire.

APPENDIX A

INDUSTRIAL DYNAMICS DATA
(TIME-SHARING SUBJECTS)

| Subject No. | #929-1a | #929-1b | #929-2 | #929-3a | #929-3b | #929-4 | #929-5a | #929-5b | #929-6 |
|-------------|---------|---------|--------|---------|---------|--------|---------|---------|--------|
| 01 | | | | | | | | | |
| 03 | 8 | 12 | 3 | 20 | 17 | 2 | 15 | 16 | 26 |
| 05 | | | | | | | | | |
| 08 | 4 | 15 | 3 | 12 | 17 | 3 | 12 | 17 | 18 |
| 09 | 3 | 16 | 2 | 9 | 17 | 1 | 3 | 16 | 15 |
| 11 | 4 | 17 | 1 | 4 | 16 | 1 | 4 | 17 | 9 |
| 13 | 2 | 11 | 3 | 10 | 15 | 3 | 10 | 15 | 22 |
| 17 | 1 | 13 | 3 | 6 | 17 | 3 | 6 | 17 | 12 |
| 19 | | | | | | | | | |
| 22 | | | | | | | | | |
| 66 | 8 | 14 | 3 | 8 | 14 | 3 | 8 | 14 | 25 |
| 26 | 3 | 14 | 1 | 3 | 14 | 1 | 3 | 14 | 11 |
| 29 | 5 | 17 | 3 | 6 | 18 | 3 | 6 | 18 | 10 |
| 30 | 3 | 16 | 2 | 3 | 16 | 2 | 3 | 16 | 20 |
| 31 | 4 | 11 | 2 | 9 | 16 | 2 | 10 | 16 | 20 |
| 34 | 4 | 10 | 3 | 8 | 12 | 4 | 8 | 12 | 30 |
| 36 | 8 | 16 | 4 | 8 | 16 | 4 | 8 | 16 | 13 |
| 37 | | | | | | | | | |
| 40 | 3 | 18 | 4 | 4 | 18 | 2 | 3 | 18 | 5 |
| 41 | 6 | 14 | 4 | 12 | 17 | 4 | 9 | 15 | 15 |
| 42 | | | | | | | | | |
| 43 | 4 | 13 | 1 | 8 | 15 | 1 | 8 | 15 | 13 |
| 45 | | | | | | | | | |
| 46 | 3 | 13 | 3 | 7 | 16 | 3 | 7 | 16 | 11 |
| 47 | 4 | 11 | 2 | 4 | 11 | 2 | 4 | 11 | 10 |
| 48 | 3 | 12 | 2 | 4 | 12 | 1 | 3 | 12 | 16 |
| 50 | 3 | 15 | 1 | 3 | 15 | 1 | 3 | 15 | 17 |
| 51 | 2 | 13 | 2 | 5 | 15 | 1 | 2 | 13 | 9 |
| 53 | 4 | 16 | 2 | 7 | 17 | 2 | 7 | 17 | 16 |
| 56 | 8 | 14 | 3 | 8 | 14 | 3 | 8 | 14 | 10 |
| 59 | 2 | 12 | 3 | 5 | 15 | 3 | 5 | 15 | 13 |
| 63 | 3 | 15 | 1 | 6 | 15 | 1 | 6 | 15 | 16 |
| 64 | 9 | 15 | 3 | 15 | 16 | 1 | 9 | 15 | 35 |

APPENDIX A

INDUSTRIAL DYNAMICS DATA
(TIME-SHARING SUBJECTS)

| Subject No. | #929-7a | #929-7b | #929-7c | #929-7d | #929-7e | #929-7f | #929-8 | #929-9 |
|-------------|---------|---------|---------|---------|---------|---------|--------|--------|
| 01 | | | | | | | | |
| 03 | 5 | 50 | 5 | 15 | 25 | | 7 | 15 |
| 05 | | | | | | | | |
| 08 | | 30 | | 40 | 10 | | 8 | 11 |
| 09 | 10 | 20 | 10 | 30 | 20 | | 7 | 10 |
| 11 | 10 | 80 | 10 | | | | 8 | 3 |
| 13 | 10 | 20 | 20 | 30 | 20 | | 9 | 17 |
| 17 | 10 | 20 | 30 | 10 | 25 | 5 | 4 | 0 |
| 19 | | | | | | | | |
| 22 | | | | | | | | |
| 66 | 10 | 40 | 7 | 8 | 20 | 5 | 9 | 12 |
| 26 | | 25 | 10 | 10 | 25 | | 7 | 4 |
| 29 | 30 | 20 | | 10 | 30 | 10 | 3 | 3 |
| 30 | | 25 | | 15 | 10 | 25 | 8 | 12 |
| 31 | 10 | 50 | 20 | 10 | 10 | | 8 | 7 |
| 34 | | 25 | 50 | 10 | 14 | 1 | 7 | 5 |
| 36 | | 20 | 20 | 30 | 10 | | 7 | 4 |
| 37 | | | | | | | | |
| 40 | 25 | 25 | | 30 | 20 | | 3 | 0 |
| 41 | 20 | 60 | 4 | 4 | 10 | 2 | 7 | 4 |
| 42 | | | | | | | | |
| 43 | 15 | 25 | 10 | 15 | 20 | 10 | 3 | 5 |
| 45 | | | | | | | | |
| 46 | 30 | 25 | 5 | 15 | 20 | 5 | 2 | 2 |
| 47 | 20 | 40 | 30 | 20 | 20 | | 9 | 3 |
| 48 | 5 | 20 | 25 | 10 | 10 | 5 | 7 | 6 |
| 50 | | | 10 | 10 | 10 | 50 | 7 | 8 |
| 51 | | 40 | 10 | 10 | 10 | 10 | 5 | 3 |
| 53 | | 20 | 15 | 20 | 10 | 10 | 6 | 4 |
| 56 | 10 | 30 | 10 | 5 | 40 | 10 | 4 | 3 |
| 59 | 20 | 20 | 20 | 15 | 15 | | 8 | 7 |
| 63 | 20 | 45 | 15 | 5 | 20 | | 8 | 8 |
| 64 | 15 | 30 | 10 | 15 | 30 | | 7 | 10 |

APPENDIX A

INDUSTRIAL DYNAMICS DATA
(TIME-SHARING SUBJECTS)

| Subject No. | Grade A | Grade B | Grade C | Grade D | Maximum Performance |
|-------------|---------|---------|---------|---------|---------------------|
| 01 | 7 | 10 | 2 | 6 | 1650 |
| 03 | 8 | 7 | 5 | 6 | 1000 |
| 05 | | | | | |
| 08 | 12 | 13 | 2 | 5 | 1600 |
| 09 | | | | | |
| 11 | 5 | 5 | 0 | 5 | |
| 13 | 12 | 12 | 5 | 6 | 1580 |
| 17 | 10 | 12 | 0 | 5 | 1500 |
| 19 | 12 | 15 | 10 | 6 | 1300 |
| 22 | | | | | |
| 66 | 15 | 8 | 10 | 5 | 1800 |
| 26 | 15 | 15 | 8 | 9 | 1550 |
| 29 | 9 | 6 | 1 | 3 | 1100 |
| 30 | 11 | 5 | 0 | 2 | 1575 |
| 31 | 7 | 5 | 0 | 3 | 1500 |
| 34 | 12 | 8 | 3 | 9 | 1500 |
| 36 | 5 | 7 | 0 | 3 | 1475 |
| 37 | | | | | |
| 40 | | | | | |
| 41 | 7 | 5 | 3 | 5 | 1538 |
| 42 | | | | | |
| 43 | 11 | 11 | 8 | 9 | 1500 |
| 45 | | | | | |
| 46 | 10 | 14 | 7 | 8 | 1675 |
| 47 | 6 | 7 | 1 | 7 | 1250 |
| 48 | 11 | 6 | 0 | 3 | 1550 |
| 50 | 2 | 2 | 0 | 2 | 1525 |
| 51 | 10 | 8 | 3 | 6 | 1550 |
| 53 | 14 | 7 | 0 | 6 | 1050 |
| 56 | 5 | 15 | 9 | 9 | 1200 |
| 59 | 8 | 6 | 0 | 3 | 1350 |
| 63 | 11 | 7 | 0 | 4 | 1250 |
| 64 | 12 | 9 | 2 | 4 | 1550 |

APPENDIX B

**INDUSTRIAL DYNAMICS DATA
(BATCH-PROCESSING SUBJECTS)**

APPENDIX B

INDUSTRIAL DYNAMICS DATA
(BATCH-PROCESSING SUBJECTS)

| Subject No. | #926-1 | #926-2 | #926-3 | #926-4 | #926-5 | #926-6 | #927-1 | #927-2 | #927-3a | #927-3b | #927-3c | #927-3d |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|---------|---------|
| 16 | 4 | 5 | 1 | 1 | 4 | 7 | y | 120 | 75 | 25 | | |
| 07 | 4 | 5 | 1 | 7 | 5 | 9 | | | | | | |
| 21 | 1 | 1 | 1 | | 2 | 2 | n | | | | | |
| 28 | 2 | 2 | | | 4 | 7 | y | 120 | 80 | 20 | | |
| 23 | 1 | 1 | 1 | | 1 | 4 | n | | | | | |
| 52 | | | | | | | | | | | | |
| 49 | 1 | 2 | 1 | | 1 | | y | 60 | | | | |
| 58 | 1 | 1 | | 3 | 1 | 3 | y | 180 | 33 | 17 | | 50 |
| 25 | 2 | 2 | 1 | | 2 | 8 | y | 90 | 33 | | 33 | 34 |
| 65 | 2 | 2 | | | 2 | 2 | n | | | | | |
| 67 | 3 | 3 | 1 | | 3 | 5 | n | 30 | 100 | | | |
| 60 | 1 | 1 | 1 | 1 | 2 | 3 | y | 45 | 60 | 40 | | |
| 02 | | | | | | | | | | | | |
| 32 | 1 | 1 | | | 2 | 3 | n | | | | | |
| 18 | 3 | 3 | 1 | 5 | 4 | 7 | n | | | | | |
| 38 | 2 | 2 | 3 | 2 | 3 | 6 | n | | | | | |
| 10 | 2 | 2 | 1 | 4 | 3 | 7 | n | | | | | |
| 61 | 1 | 1 | 1 | | 1 | 6 | y | 240 | 50 | 10 | | 30 |
| 54 | | | | | | | | | | | | |
| 33 | 1 | 3 | 1 | 2 | 3 | 8 | y | 120 | 75 | 25 | | |
| 35 | 2 | 2 | 3 | 3 | 3 | 7 | y | 120 | 25 | 25 | | |
| 12 | | | | | | | | | | | | |
| 55 | 2 | 3 | | | 3 | 7 | y | 120 | 75 | 25 | | |
| 27 | 4 | 3 | | | 4 | 6 | y | 180 | 80 | 20 | | |
| 39 | 6 | 6 | 3 | 2 | 5 | 6 | y | 180 | 80 | 20 | | |
| 44 | 2 | 2 | 1 | | 2 | 7 | n | | | | | |
| 57 | 1 | 1 | 1 | | 1 | 8 | y | 30 | 67 | 33 | | |
| 24 | 3 | 3 | 1 | 5 | 3 | 8 | y | 150 | 50 | | | 50 |
| 15 | 1 | 1 | 1 | 3 | 5 | 9 | y | 60 | 90 | | | 10 |
| 06 | 1 | 1 | 1 | | 1 | 5 | n | | | | | |
| 14 | 1 | 1 | 1 | | 3 | 9 | y | 120 | 40 | 25 | | 35 |
| 04 | 1 | 1 | 1 | 1 | 3 | y | n | | | | | |
| 20 | 1 | 1 | 1 | 5 | 1 | 8 | n | | | | | |

APPENDIX B

INDUSTRIAL DYNAMICS DATA
(BATCH-PROCESSING SUBJECTS)

| Subject No. | #928-1 | #928-2a | #928-2b | #928-3 | #928-4 | #928-5 | #928-1* | #928-2* | #928-3* | #928-4* | #928-5* | #928-6* |
|-------------|--------|---------|---------|--------|--------|--------|---------|---------|---------|---------|---------|---------|
| 16 | | | | | | | | | | | | |
| 07 | | | | | | | | | | | | |
| 21 | n | | 28 | 1 | 1 | 7 | 2 | 2 | 1 | 1 | 3 | 5 |
| 28 | y | 18 | | 5 | 4 | 7 | 3 | 3 | 2 | 5 | 3 | 7 |
| 23 | n | | | 1 | 1 | 9 | 5 | 5 | 1 | 1 | 3 | 7 |
| 52 | | | | | | | | | | | | |
| 49 | n | | 8 | 7 | 4 | 8 | 6 | 6 | 5 | 4 | 4 | 7 |
| 58 | n | | 8 | 7 | 6 | 9 | 2 | 2 | 1 | 5 | 2 | 7 |
| 25 | | | | | | | | | | | | |
| 65 | n | | | 1 | 1 | 9 | 3 | 3 | 2 | 1 | 3 | 8 |
| 67 | n | | 8 | 4 | 2 | 7 | 4 | 4 | 3 | 2 | 4 | 7 |
| 60 | | | | | | | | | | | | |
| 02 | | | | | | | | | | | | |
| 32 | | | | | | | | | | | | |
| 18 | n | | 12 | 1 | 1 | 9 | 2 | 2 | 1 | 1 | 3 | 9 |
| 38 | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | |
| 61 | y | 20 | | 2 | 2 | 7 | 2 | 3 | 1 | 2 | 3 | 7 |
| 54 | y | | | 3 | 3 | 7 | 5 | 5 | 5 | 3 | 5 | 7 |
| 33 | n | | 8 | 6 | 4 | 9 | 4 | 4 | 3 | 4 | 6 | 8 |
| 35 | n | | 8 | 3 | 2 | 8 | 5 | 5 | 4 | 3 | 4 | 8 |
| 12 | | | | | | | | | | | | |
| 55 | y | 17 | | 4 | 7 | 8 | 4 | 6 | 6 | 1 | 4 | 7 |
| 27 | y | 18 | | 8 | 7 | 8 | 6 | 5 | 6 | 7 | 6 | 7 |
| 39 | n | | 8 | 5 | 4 | 7 | 5 | 5 | 5 | 5 | 3 | 7 |
| 44 | y | 18 | | 3 | 9 | 9 | 6 | 5 | 4 | 2 | 1 | 8 |
| 57 | n | | 8 | 3 | 4 | 9 | 3 | 3 | 1 | 2 | 4 | 9 |
| 24 | n | | 8 | 7 | 7 | 9 | 5 | 5 | 4 | 3 | 4 | 7 |
| 15 | n | | 4 | 5 | 2 | 7 | 2 | 3 | 2 | 2 | 2 | 7 |
| 06 | y | 16 | | 5 | 8 | 7 | 2 | 2 | 1 | 7 | 2 | 9 |
| 14 | y | 18 | | 5 | 8 | 9 | 5 | 6 | 6 | 4 | 5 | 9 |
| 04 | y | 17 | | 6 | 9 | 9 | 4 | 4 | 5 | 6 | 3 | 9 |
| 20 | | | | | | | | | | | | |

* These refer to the second page of the questionnaire.

APPENDIX B

INDUSTRIAL DYNAMICS DATA
(BATCH-PROCESSING SUBJECTS)

| Subject No. | #929-1a | #929-1b | #929-2 | #929-3a | #929-3b | #929-4 | #929-5a | #929-5b | #929-6 |
|-------------|---------|---------|--------|---------|---------|--------|---------|---------|--------|
| 16 | 6 | | 12 | 25 | | 9 | 15 | | 30 |
| 07 | 3 | 11 | 2 | 7 | 15 | 2 | 7 | 15 | 12 |
| 21 | 8 | 16 | 1 | 25 | 17 | 1 | 25 | 17 | 27 |
| 28 | 2 | 14 | 2 | 5 | 16 | 2 | 5 | 16 | 12 |
| 23 | 10 | 18 | 1 | 10 | 18 | 1 | 3 | 16 | 10 |
| 52 | | | | | | | | | |
| 49 | 4 | 12 | 2 | 1 | 14 | 1 | 10 | 17 | 24 |
| 58 | 2 | 10 | 2 | 20 | 16 | 2 | 20 | 16 | 30 |
| 25 | 4 | 13 | 3 | 10 | 17 | 3 | 12 | 17 | 13 |
| 65 | 10 | 18 | 2 | 3 | 19 | 2 | 13 | 19 | 13 |
| 67 | 6 | 15 | 2 | 2 | 16 | 1 | 6 | 15 | 10 |
| 26 | | | | | | | | | |
| 02 | 5 | | 2 | 10 | 16 | 2 | 10 | 16 | 17 |
| 32 | | | | | | | | | |
| 18 | 20 | | 1 | 20 | | 1 | 20 | | 25 |
| 38 | | | | | | | | | |
| 10 | | | | | | | | | |
| 61 | 5 | 12 | 3 | 9 | 16 | 1 | 7 | 15 | 16 |
| 54 | 15 | 14 | 2 | 25 | 18 | 2 | 25 | 18 | 30 |
| 33 | 3 | 11 | 4 | 17 | 17 | 3 | 16 | 16 | 18 |
| 35 | 3 | 14 | 1 | 10 | 17 | 1 | 10 | 17 | 13 |
| 12 | | | | | | | | | |
| 55 | 6 | 14 | 3 | 17 | 17 | 3 | 17 | 17 | 22 |
| 27 | 4 | | 3 | 6 | | 3 | 6 | | 12 |
| 39 | | | | | | | | | |
| 44 | | | | | | | | | |
| 57 | 4 | 11 | 4 | 20 | 16 | 4 | 20 | 16 | 40 |
| 24 | 3 | 14 | 4 | 12 | 17 | 4 | 12 | 17 | 23 |
| 15 | 5 | 15 | 2 | 10 | 24 | 1 | 5 | 15 | 12 |
| 06 | 2 | 11 | 2 | 3 | 11 | 2 | 3 | 11 | 13 |
| 14 | 2 | | 2 | 5 | | 2 | 5 | | 11 |
| 04 | 3 | 12 | 2 | 20 | 15 | 2 | 20 | 15 | 25 |
| 20 | 5 | 16 | 3 | 10 | 17 | 3 | 10 | 17 | 17 |

APPENDIX B

INDUSTRIAL DYNAMICS DATA
(BATCH-PROCESSING SUBJECTS)

| Subject No. | #929-7a | #929-7b | #929-7c | #929-7d | #929-7e | #929-7f | #929-8 | #929-9 |
|-------------|---------|---------|---------|---------|---------|---------|--------|--------|
| 16 | 10 | 20 | 10 | 20 | 30 | 10 | 8 | 10 |
| 07 | 2 | 20 | 3 | 15 | 20 | 30 | 6 | 4 |
| 21 | 50 | 40 | | 10 | | | 7 | 15 |
| 28 | 10 | 60 | 10 | 20 | | | 4 | 3 |
| 23 | 25 | 25 | | 25 | | 25 | 6 | 4 |
| 52 | | | | | | | | |
| 49 | 20 | 20 | 10 | 5 | 25 | 20 | 9 | 8 |
| 58 | | 10 | 10 | 50 | 10 | 20 | 8 | 10 |
| 25 | 20 | 10 | | 30 | 20 | 20 | 6 | 6 |
| 65 | 50 | 20 | 10 | 20 | | | 6 | 8 |
| 67 | 20 | 30 | 10 | 20 | 20 | | 4 | |
| 60 | | | | | | | | |
| 02 | | 25 | 20 | 20 | 25 | 10 | 6 | 10 |
| 32 | | | | | | | | |
| 18 | | | | 5 | 5 | 90 | 9 | 25 |
| 38 | | | | | | | | |
| 10 | | | | | | | | |
| 61 | 10 | 10 | | 5 | 40 | 10 | 8 | 6 |
| 54 | 5 | 50 | 5 | 15 | 20 | 5 | 7 | 15 |
| 33 | 20 | 30 | 20 | 10 | 20 | | 7 | 10 |
| 35 | 50 | 25 | 10 | 5 | 10 | | 2 | 2 |
| 12 | | | | | | | | |
| 55 | 15 | 30 | 10 | 10 | 25 | 10 | 4 | 7 |
| 27 | | 10 | 10 | 20 | 45 | | 3 | 2 |
| 39 | | | | | | | | |
| 44 | | | | | | | | |
| 57 | 2 | 3 | 2 | 1 | 90 | | 9 | 34 |
| 24 | 5 | 40 | 15 | 5 | 30 | 5 | 7 | 10 |
| 15 | 15 | 2 | 25 | 10 | 10 | 10 | 7 | 3 |
| 06 | 8 | 15 | 15 | 25 | 8 | 4 | 1 | 1 |
| 14 | 10 | 15 | 25 | 15 | 20 | 15 | 5 | 4 |
| 04 | 20 | 50 | 5 | 10 | 15 | | 9 | 10 |
| 20 | 20 | 30 | 10 | 10 | 30 | | 9 | 10 |

APPENDIX B

INDUSTRIAL DYNAMICS DATA
(BATCH-PROCESSING SUBJECTS)

| Subject No. | Grade A | Grade B | Grade C | Grade D | Maximum Performance |
|-------------|---------|---------|---------|---------|---------------------|
| 16 | 8 | 10 | 2 | 5 | 1600 |
| 07 | | | | | |
| 21 | 5 | 8 | 0 | 5 | 1050 |
| 28 | 14 | 14 | 9 | 8 | 1425 |
| 23 | 5 | 5 | 0 | 2 | |
| 52 | | | | | |
| 49 | 15 | 5 | 0 | 4 | 1275 |
| 58 | 14 | 10 | 6 | 5 | 1250 |
| 25 | 10 | 3 | 0 | 3 | 1000 |
| 65 | | | | | |
| 67 | | | | | |
| 60 | | | | | |
| 02 | 10 | 15 | 2 | 6 | 1150 |
| 32 | | | | | |
| 18 | 7 | 10 | 2 | 4 | |
| 38 | | | | | |
| 10 | 5 | 5 | 0 | 0 | |
| 61 | 8 | 5 | 0 | 2 | 1100 |
| 54 | 15 | 5 | 0 | 2 | 1100 |
| 33 | 8 | 10 | 4 | 2 | 1300 |
| 35 | 10 | 5 | 1 | 3 | 1050 |
| 12 | | | | | |
| 55 | | | | | |
| 27 | 10 | 5 | 1 | 3 | 1100 |
| 39 | 8 | 5 | 0 | 1 | |
| 44 | 14 | 6 | 0 | 3 | 1000 |
| 57 | 10 | 10 | 8 | 4 | 1035 |
| 24 | 6 | 5 | 0 | 4 | 1050 |
| 15 | 12 | 8 | 2 | 5 | 1100 |
| 06 | 10 | 10 | 2 | 5 | 1521 |
| 14 | 12 | 12 | 8 | 5 | 1550 |
| 04 | 10 | 15 | 10 | 8 | 1630 |
| 20 | 13 | 15 | 5 | 5 | 1600 |

APPENDIX C

INDUSTRIAL DYNAMICS QUESTIONNAIRES

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
Industrial Dynamics Research

INDUSTRIAL DYNAMICS RESEARCH GROUP INFORMATION

During this semester, the Industrial Dynamics Research Group will be conducting an investigation of students' allocation of time and effort on an Industrial Dynamics project. A portion of this study will involve an investigation of the methods used by the members of the Industrial Dynamics course to complete the "Construction Industry" assignment.

In order that this phase of the investigation might be carried out effectively, the active cooperation of the students in this course will be required. As a result you will receive questionnaires to complete during the period of this assignment. In order to minimize the extra work, these have been designed to require an extremely short amount of time to complete.

The first of these questionnaires will be found following this information sheet. (It contains the "Student Code Number" that will be used to identify your questionnaires for statistical analysis). Please complete the questions and return the questionnaire in the enclosed envelope.

NOTE: Your instructor will receive no information concerning your answers to the questionnaires. Your answers to these questionnaires will have no effect upon your grade for this assignment or course. However, since the completion of these questionnaires is a requirement of this course, your instructor will be notified of failure to complete them.

D-927

Student Code Number: _____

Instructions for Construction Industry Assignment

CORRECTION: The Profit Rate (PR and PR1) in the model should be considered the average profit per apartment unit sold because it is calculated as the total profit from all apartment units sold divided by the total number of apartment units.

INSTRUCTIONS: While working on the Construction Industry assignment, DYNAMO will be available for your use only on the time-sharing system. In order to use this system, teletype consoles with time-sharing time will be available in Room 52-076A between 9:30 am to midnight from Wednesday, March 9th through Friday, March 18th (including Saturday and Sunday the 12th and 13th).

Copies of the Construction Industry program (see List 2 from the assignment) will be available on the time-sharing system -- the name of the program will be a combination of your two initials and the Student Code Number. For example, if your name were John Doe and the number above were 01, then the name of your program would be JD-01. In case of difficulty, there will be someone available in this console room to help you with any time-sharing problems.

After your analysis of each computer run, you must fill out a questionnaire for that run (you must fill out a separate questionnaire for each re-run as well). These questionnaires will be available in the console room and, in order to minimize the extra work, have been designed to require an extremely short amount of time to complete. Please complete them immediately after you finish analyzing your results and return them in the envelope enclosed with the questionnaire.

Fill out the questionnaire on the following page immediately and return it in the enclosed envelope.

NOTE: Your instructor will receive no information concerning your answers to the questionnaires. Your answers to these questionnaires will have no effect upon your grade for this assignment or course. However, since the completion of these questionnaires is a requirement of this course, your instructor will be notified of failure to complete them.

D-927

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
Industrial Dynamics Research

Student Code Number: _____

1. Have you begun work on the "Construction Industry" assignment? _____
2. If you have, how much time have you spent on it? _____ hours
3. Approximately what percentage of the total time was spent on the following:
 - a Analyzing the written description _____%
 - b Analyzing the flow diagrams _____%
 - c Analyzing the plotted output _____%
 - d Writing equations _____%
 - e Other (specify) _____%

D-927

Student Code Number: _____

Instructions for Construction Industry Assignment

CORRECTION: The Profit Rate (PR and PR1) in the model should be considered the average profit per apartment unit sold because it is calculated as the total profit from all apartment units sold divided by the total number of apartment units.

INSTRUCTIONS: While working on the Construction Industry assignment, DYNAMO will be available for your use only on the batch-processing system. Input will be sent to the computer at 10:45 am and 10:45 pm with results returned during the afternoon for the morning run and very early the morning after the evening run. This will continue from Wednesday, March 9th through Friday, March 18th (including Saturday and Sunday, the 12th and 13th). In addition, computer time has been reserved on the Sloan School's 1620 computer at 8:50, 9:20, 9:50 and 10:20 for morning use of the DYNAMO pre-compiler for check-outs, and at 2, 3, and 4 for afternoon use. Please use the JOB cards available in the Computer Facility for your runs.

Copies of the Construction Industry program (see List 2 from the assignment) are included with these instructions -- the program name is a combination of your two initials and the Student Code Number. For example, if your name were John Doe and the number above were 01, then the name of your deck would be JD-01 and could be found on your deck and your program's ID card. Please use the same name for all copies of this deck.

After your analysis of each computer run, you must fill out a questionnaire for that run (you must fill out a separate questionnaire for each re-run as well). These questionnaires, in addressed envelopes, will be available on the 5th floor of the Sloan Building where you leave your program decks to be run. In order to minimize the extra work, these questionnaires have been designed to require an extremely short amount of time to complete. Please complete them immediately after you finish analyzing your results and return them in the envelope enclosed with the questionnaire.

Fill out the questionnaire on the following page immediately and return it in the enclosed envelope.

NOTE: Your instructor will receive no information concerning your answers to the questionnaires. Your answers to these questionnaires will have no effect upon your grade for this assignment or course. However, since the completion of these questionnaires is a requirement of this course, your instructor will be notified of failure to complete them.

D-927

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
Industrial Dynamics Research

Student Code Number: _____

1. Have you begun work on the "Construction Industry" assignment? _____
2. If you have, how much time have you spent on it? _____ hours
3. Approximately what percentage of the total time was spent on the following:
 - a Analyzing the written description _____%
 - b Analyzing the flow diagrams _____%
 - c Analyzing the plotted output _____%
 - d Writing equations _____%
 - e Other (specify) _____%

D-928

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
Industrial Dynamics Research

PLEASE COMPLETE THIS QUESTIONNAIRE WHEN YOU HAND IN YOUR
CONSTRUCTION INDUSTRY CASE AND RETURN IT IN THE
ENCLOSED ENVELOPE.

Date: _____

Student Code Number: _____

1. Have you had sufficient time to complete your analysis of the Construction Industry case? _____

2. a) If your answer to question 1 is yes, when did you complete your analysis? _____
b) If your answer to question 1 is no, how much more time would you have needed to complete your analysis? _____

3. How useful was the computer system you used (batch-processing or time-sharing) in helping you solve the Construction Industry case?

| | | | | | | | | |
|--------------|---|---|---|---|---|---|---|----------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Use- less | | | | | | | | Very useful |

4. How satisfied are you with your final results?

| | | | | | | | | |
|---------------|---|---|---|---|---|---|---|-------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Not at all | | | | | | | | Completely satisfied |

5. How useful would the other computer system have been in helping you solve the Construction Industry case?

| | | | | | | | | |
|--------------|---|---|---|---|---|---|---|----------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Use- less | | | | | | | | Very useful |

NOTE: Your instructor will receive no information concerning your answers to the questionnaires. Your answers to these questionnaires will have no effect upon your grade for this assignment or course. However, since the completion of these questionnaires is a requirement of this course, your instructor will be notified of failure to complete them.

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
Industrial Dynamics Research

1. How much experience have you had writing DYNAMO programs?

1 2 3 4 5 6 7 8 9
Very A great
little deal

2. How much experience have you had analyzing Industrial Dynamics problems?

1 2 3 4 5 6 7 8 9
Very A great
little deal

3. How much experience have you had using DYNAMO on the Batch-processing computer system?

1 2 3 4 5 6 7 8 9
Very A great
little deal

4. What is the value of the Batch-processing system in helping you analyze Industrial Dynamics problems?

1 2 3 4 5 6 7 8 9
Very A great
little deal

5. How much experience have you had using DYNAMO on the Time-sharing computer system?

1 2 3 4 5 6 7 8 9
Very A great
little deal

6. What is the value of the Time-sharing system in helping you analyze Industrial Dynamics problems?

1 2 3 4 5 6 7 8 9
Very A great
little deal

D-925

Massachusetts Institute of Technology
Alfred P. Sloan School of Management
Industrial Dynamics Research

Date: _____ Time: _____^{am}_{pm} Student Code Number: _____

Instructions for Questionnaire Completion

- The enclosed set of questions must be filled out after you complete your analysis of each computer run submitted and prior to the submitting of your next run. Re-runs should be considered a separate run and a questionnaire should be submitted for each one.
- The pre-addressed envelopes should be used to return the questionnaires daily.

NOTE: Your instructor will receive no information concerning your answers to the questionnaires. Your answers to these questionnaires will have no effect upon your grade for this assignment or course. However, since the completion of these questionnaires is a requirement of this course, your instructor will be notified of failure to complete them.

THIS PAGE MUST BE FILLED OUT AFTER YOU COMPLETE YOUR ANALYSIS OF EACH COMPUTER RUN SUBMITTED AND PRIOR TO THE SUBMITTING OF YOUR NEXT RUN OR RUNS.

1. How much time have you expended on this problem since you last submitted a run (if this is your first run, "How much time have you expended on this problem since you began work on it?") _____ Hours

2. Approximately what percentage of this time was spent on the following:
 - a Reacquaintance with problem _____%
 - b Designing decision policies _____%
 - c Editing the program _____%
 - d Analyzing results _____%
 - e Exclusively waiting for results _____%
 - f Other (specify) _____%

3. What were your objectives in making the current changes? (rank in order of importance if more than one)
 - a Introduce other factors into existing decision rule _____
 - b Try a totally new decision rule _____
 - c Re-run to try different constants _____
 - d Correct previously undetected program errors _____
 - e Other _____

4. How effective were the results in attaining the most important objectives above?

| | | | | | | | | |
|----------|---|---|---|---|---|---|---|-----------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Ineffec- | | | | | | | | Very |
| tive | | | | | | | | effective |

5. Which of the following problems were evident from your analysis of the results? (rank in order of importance)
 - a Program didn't run -- typing error _____
 - b Program didn't run -- programming error _____
 - c Program didn't run -- other error _____
 - d Changes didn't cause expected results _____
 - e Further manipulation of decision rule required _____
 - f Further manipulation of constants required _____
 - g Other (specify) _____

6. How useful were the results of the compute run in attaining your overall objectives?

| | | | | | | | | |
|------|---|---|---|---|---|---|---|--------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Use- | | | | | | | | Very |
| less | | | | | | | | useful |

7. At this time, how far have you progressed toward completion of the analysis needed for this assignment?

| | | | | | | | | | | |
|--------|----|----|----|----|----|----|----|----|----|-----------|
| 0% | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100% |
| Not | | | | | | | | | | Analysis |
| at all | | | | | | | | | | completed |