1-1-1976

A simulation study of one and two level hierarchical communication networks.

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A SIMULATION STUDY OF ONE AND TWO LEVEL HIERARCHICAL COMMUNICATION NETWORKS

A Dissertation Presented

By

BARRY SHANE

Submitted to the Graduate School of the
University of Massachusetts in
partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 1976

Major Subject Business Administration

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LEVEL HIERARCHICAL COMMUNICATION NETWORKS

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May 1976
(Month) (Year)

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A Simulation Study of One and Two Level Hierarchical Communication Networks

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Research employing the Communication Network Experiment paradigm (CNE) has produced inconsistent results over the last 20 years. Some of the contradictory as well as inconclusive results are in regard to the dependent variable--productivity or solution rate. These findings may have been the result of problem solving sessions of short duration (60 problems or less). Group problem solving in CNE has been recently shown to exhibit a substantial transition period marked by an acceleration in the solution rate leading to a steady state. The present study was designed in anticipation that these inconsistent findings could be resolved by including individual learning and reinforcement into the CNE paradigm during long periods of problem solving.

This study has two objectives:

(1) to develop a computer simulation model of the communication network experiment

(2) to investigate specific hypotheses, previously not investigated, concerning the effect of learning and reinforcement upon the productivity of a network.

Productivity was measured by the number of messages required to complete the Bavelas-Leavitt task.

A four-man Communication Network Experiment model was constructed to examine, (1) the transition states in learning and (2) productivity for a Circle and an All-Channel network. The major features of the model were:

(1) A set of messages and channels which:

   (a) lead to a solution of the problem
   (b) influence behavior patterns

(2) A set of rules which:

   (a) provided for probabilistic changes of messages and channels
   (b) permit non-optimal performance but require logical consistency in problem solution
   (c) identify 'good' behavior and tend to have it repeated
   (d) allow certain kinds of effective behavior to develop over the course of a number of trials by 'recognizing' both desirable and undesirable behavior.

(3) A set of initial program parameters which are altered during the course of the simulation.

Based on the following three step validation procedure, the simulation model appeared to be a reasonable representation of subjects in CNE. The first step indicated the model's reliability. Reliability is defined as the ability of the model to produce consistent time-series regardless of the sequence of pseudo-random numbers used to drive the model. Model reliability was determined by comparing the estimates of the regression equation for the original and replicated runs along with the coefficients of determination.

Two more validation steps required a comparison of the data with the results of the Burgess long term CNE laboratory study for 'goodness of fit'. A comparison was made between the simulated and laboratory data of a Circle network for overall fit and to establish similarities in the breaks or onset of the transition states of learning.

The effects of learning and reinforcement on productivity in problem solving were assessed for the All-Channel network (a two level hierarchy) and then compared with a Circle network (a one level hierarchy). The findings are:

(1) In the long run, productivity measured by number of messages required for solution for both Circle and All-Channel networks is similar.

(2) Solution rates measured by solutions per trial are similar for Circle and All-Channel networks, in the long run.

(3) The fewer the levels of hierarchical structure, the sooner an optimal rate of productivity may be reached. All-Channel networks reach a steady state solution rate in fewer cumulative solutions than Circle networks.

In general, the findings demonstrated the importance of including learning and reinforcement into the CNE paradigm. Differences may have existed in the CNE of short duration. However, these may not have been significant differences when compared to cumulative experiences of longer duration. As the findings of this study and data from individual psychology suggest, problem solving is composed of transition states in learning. Therefore, rather than being concerned with tests of significance and employing large samples for short periods of time, a more effective strategy would seem to be to examine smaller samples for a relatively extended period of time.

CHAPTER I

INTRODUCTION

Background

Substantial effort has been exerted by social psychologists to reduce the interplay of individuals to a manageable level for theorizing. Considerable emphasis has been placed upon designing experimental tasks and settings simple enough to permit observation of groups processes, yet not so simple that the essence of group interaction is dissipated.

The associated studies of group dynamics and sociometric analysis have proceeded along two avenues. First, some degree of success has been achieved by reducing the interplay of individuals to a single event, similar to the Asch experiment. This one observable act, however, provides scant substance for theorizing. Second, the more involved methods of experimenting with group processes have been so thick in interaction that only a few variables can be reduced to quantifiable form and analyzed.

The communication network experiment has been one of the compromises to these approaches. By foregoing the detail of face-to-face interaction and exposing the behavior of group members in a series of observable acts, sufficient variables are controlled to permit a systematic analysis of quantifiable data. Concern for the effects of different patterns of interaction upon group processes led to the initial interest in the Communication Network Experiments (CNE). These experiments were one strategy for the study of group structures under controlled conditions.

The primary purpose of this study is to contribute to the integration of these two approaches. This will be achieved by developing a computer simulation model of CNE and investigating a general hypothesis concerning the effects of learning and reinforcement upon network productivity.

Statement of the Original CNE Problem. Bavelas (1950) originally defined the problem as follows:

> Imposed patterns of communication may determine certain aspects of group processes. This raises the question of how a fixed communication pattern may affect the work life of a group. Do certain patterns have structural properties which may limit group performance? May it be that several communication patterns are all logically adequate for the successful completion of a specified task? Or will one result in significantly better performance than another?

With these questions Bavelas developed the experimental procedures, now standard in CNE, which have been systematically built upon in an attempt to construct a theoretical framework and subject it to empirical tests.

Due to the formal theoretical emphasis of Bavelas' original work and the ensuing popularity of his experimental technique, many investigators have been disappointed that the research findings on communication networks have not led to a rigorous theory of group structure.

Davis (1969) noted that although the experimental method has enabled researchers to use observable individual behaviors as the foundation for cumulative empirical relationships, the amount of confusion which has occurred in the study of networks is surprising. The lack of unifying concepts seems to warrant further elemental research. Burgess (1968) observed that groups appear to organize in specific schemes and perform at speeds independent of communication freedom and of the network in which the group is operating.

Several criticisms may be leveled against most CNE to date. Two are of primary concern. First, data from psychology have indicated that during individual learning there are three distinct phases--an initial transition period, a period of acceleration in response rates, and then a 'steady state' in response rates. Once this phase is reached, behavior remains typically stable for long periods. To date, only one of the CNE was designed or conducted in such a way that a steady state could be achieved. Consequently, groups may have been either in the process of organizing or searching for the optimal sequences of messages when the experiments were terminated. If the data from individual psychology suggest that these transition states are the rule rather than the exception, the research strategy for CNE should be reversed. Rather than manipulate large samples for short time periods, smaller samples should be examined for a longer duration to determine the effects of learning. Also, previous studies failed to include a basic property of social interaction behavioral consequences of either positive or negative reinforcement. This seems particularly critical since the literature (Staats and Staats, 1964) indicates that most behavior, or change in behavior, is predicted upon environmental consequences perceived or imagined.

To date CNE have been marked by inconclusive and inconsistent findings. (Collins and Raven, 1969) Reexamining the last three questions posed originally by Bavelas, one can still not find satisfactory explanations for what may be missing variables or relationships.

Previous Research in CNE. The Bavelas-Leavitt[1] (1950-1951) experiment has been followed by a large number of studies employing the communication network paradigm. The voluminous research has been collected and synthesized in three comprehensive reviews. The first is by Glanser and Glazer (1961) who note that (p. 13)

> "The area has been worked not only exhaustively but to exhaustion. After a promising start, the approach has led to many conflicting results that resist any neat order."

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[1] The paradigm is outlined in detail in Chapter Two.

The second review by Marvin Shaw (1964), a prolific contributor to the CNE literature, also attempts to order the seemingly conflicting results. The last review by Collins and Raven (1969), and perhaps the most comprehensive, summarized the research in tableau form categorizing the studies by task, network, independent and dependent variables, and the findings.

The results have been classified on several measures of performance--time, number of errors, number of messages to complete the task, etc. Although there are inconsistencies on any one measure, it is generally concluded that Wheel, Y, Chain, and Circle constitute an order of decreasing performance (Collins and Raven, 1969).

The first attempts to find consistent relationships among the variables thereby establishing a basis for theorizing, led to the use of structural indices. (Luce, Macy, Hay, 1954; Flament, 1963; Glanser and Glazner, 1959; and Shaw, 1964). Bavelas introduced the concept of network centrality or distance between positions, and then also suggested relative centrality. The latter correlates rather well with position performance and personal reactions to one's position in the network (Davis, 1969). But network centrality has not been as useful in predicting group-level variables such as performance. There have been other suggestions, a 'peripherality index' by Leavitt and an 'independence and saturation index' by Shaw, neither of which has satisfactorily improved the contribution to a theoretical base. In summary, no single index has been employed to explain structural characteristics for all the dependent variables that structure seems to influence. These indices have all been unsatisfactory in explaining the differences in performance between the various networks.

Collins and Raven note that "Leavitt (1951) concluded that a five person Wheel network had a lower average time on correct trials than did a five person circle. But Shaw (1954), with four person groups, reported the opposite, that circles were somewhat faster than wheels."

Contrary to Shaw's findings that the more centralized networks are faster, Burgess (1968) found that a steady solution rate is reached after prolonged experience in both centralized and decentralized networks.

Recently Collins and Raven (1969) concluded their review of the CNE literature by stating, "It is almost impossible to make a simple generalization about any variable without finding at least one study to contradict the generalization. . . ."

Clearly, 'something happens' differently in different networks, and group performance is frequently influenced in a strong way. Centrality, saturation, independence, and the other concepts aid in ordering these phenomena, but do not constitute a viable theory.

The key to the development of an orderly understanding may stem from emphasizing the role of a network's operating structure,[2] a notion reintroduced by Davis (1969). Guetzkow and Simon (1955) originally pointed out that given the opportunity to develop maximally efficient operating structures--there is no difference in the limiting times for task performance between unrestricted or decentralized networks (All-Channel) and centralized or restricted networks (Wheel and Circle).

This approach may not be as fruitful as Davis suggests. Marshall (1966) points out in his experience with the Cohen (1962) experiments that conversations with subjects after their sessions indicated that many of the subjects did not fully and accurately comprehend: (1) the network they were in (2) the optimal behavior for the network and (3) the exact nature of their own role in the network and the effects of their own activities on the development of the organization.

These comments support Shaw's argument that the evidence presented by Guetzkow et al. and used by Mulder (1959) merely shows that efficiency and organization are correlated. In fact Schein, (1958), in a series of experiments dealing with this question, found efficiency and organization perfectly correlated at the end of his

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[2] A network's operating structure is considered to be defined by the available channels open to each participant of that network.

experiment. However, achievement of efficiency developed earlier than organization. Therefore, Shaw's basic criticism stands: the support for Guetzkow hypothesis is basically correlated in nature.

More recently, Burgess (1968) integrated individual learning theory into a CNE paradigm. By specifically including learning concepts into his design, he found that Circle and Wheel networks can reach a similar steady state of performance. Although trial lengths for these two networks were significantly different (200-300 for Wheels and 500-600 for Circles) the nature of these structures became apparent. Performance of a network is a function of each member's ability to adapt to structures or environments of varying complexity. This adaption was achieved by having each member learn his role in the task-structure through information feedback and reinforcement provided through the experimental process.

Resolution of some of the preceding disparate findings may be achieved by employing a long-term study using the computer simulation approach.

Simulation. The use of computer simulation models of human behavior has been extensive during the last two decades (Dutton and Starbuck, 1971). Their use, however, has led to little systematic effort to integrate findings within a general framework. Bales (1959), Abelson (1968) and others have hailed the simulation technique as a welcome tool for further investigation of psycho-social phenomena.

Dutton and Starbuck pose perhaps the major advantage for simulation of behavior as follows:

> Simulation imposes a modest degree of logical rigor on the theorist, and encourages him to analyze the temporal structure of the modeled processes. Verbal and mathematical theories are not always complete. Because computing machines operate sequentially, a well defined temporal sequence is inherent in every operating program and the model builder is forced to specify this sequence. He must at least consider which operations precede which operations, and in so doing, takes a first step toward casual identification.

Therefore the integration of behavioral processes required for a process to be simulated demands deliberate and careful construction to synthesize past empiricism.

The phrase, computer simulation, requires some exposition. According to Dutton (1971) simulation can be defined as a duplication of a system or activity, that is, the essential characteristics of the system. It should be emphasized that the construction of a model need not take the form of, or mirror, an actual process. Inevitably a model will include some simplifying assumptions that are at variance with reality. However, some of the essential relationships which exist between the elements of the real system should be included.

Human behavior of individual system elements may be thoroughly understood, but the interrelationships of the elements, and consequently the behavior of the system or process as a whole, may not be. Here a simulation can determine and highlight the behavior of the total system in a deductive fashion.

There are several reasons why the proposed research will take the form of a computer simulation model.

1. If sufficient realism can be obtained in sets of relatively simple equations, analytical models are, in general, less time-consuming and can more easily produce optimal results than can simulations (Dutton and Briggs, 1971). The communication network experiment possesses stochatic components which exhibit a feedback property. It follows that analytical techniques would be very cumbersome with this paradigm.

2. A long-term study has been suggested by the need for the inclusion of transition states of learning. Swanson (1953) studied groups that differed in knowledge of task and amount of prior experience working together. Groups that had worked together previously on a task exceeded other groups in success of task performance and mutual satisfaction.

Most studies are not of long duration and present only a snapshot of continual behavioral processes within groups. Weick (1969) states that this depicts a static view of organizations because mechanisms associated with processes of change, development, restructuring, and fluidity are not highlighted. The simulation strategy offers more acceptable methods to overcome this criticism, because it can deal with feedback properties, stochastic elements in the process, and changes which occur throughout a specified time period.

3. Reliable data are needed for generating and testing useful theories. The use of multiple techniques which are imperfect in different ways, can resolve the generation of ambiguous data. When many of them are applied, the imperfections in each tend to check and/or amplify one another. Simulation is one of these possible techniques.

4. A theoretical model may have a number of gaps in it which are more readily perceived in the course of constructing a simulation. Certainly that appears to be evident in the present state of the current theory.

5. By constructing a simulation model in this area, one is forced to synthesize existing propositions which may otherwise remain disparate verbal or mathematical statements. Because many findings have to be incorporated to achieve a mathematical model for a simulation, the rigor of this approach tends to lend formalism to theoretical statements.

Previous CNE simulation studies. There have been previous simulation studies in the CNE. McWhinney (1964) has written a computer program to simulate communication network behavior, but was apparently not completely successful. His work involved a model with very few parameters and was not intended to provide the same sort of results as the proposed model. McWhinney tested the effects of 'local rationality' on self-organization of communication patterns. His lack of success in experimentation may be traced to the exclusion of some phenomena in group development, one of which was learning.

Marshall (1966) attempted to simulate, with a more complex set of parameters, the results of CNE conducted by Cohen (1962). His model was relatively successful in reproducing those data, but was not adaptable to slight changes in the network with which he validated his model.

The model to be proposed for experimentation differs from the previous attempts in two ways:

1. By basing the input parameters on data from a wider variety of networks, the model can be made more general in nature so as to examine more networks. Within this study, two dichotomous networks are investigated; a one level hierarchy, the Circle and a two level hierarchy, the All-Channel network.

2. Inclusion of feedback and reinforcement in individual learning should permit a closer approximation to many possible outcomes.

The Nature of This Research Study

Problem Formulation. The problem examined in this study was formulated with an exploratory general hypothesis; will the introduction of learning and reinforcement into the CNE paradigm account for differences between the networks previously mentioned? As a result of this hypothesis, two objectives were delineated.

(1) To develop a computer simulation of the communication network experiment.

(2) To investigate specific hypotheses concerning the effect of learning and reinforcement upon the productivity of a network previously not investigated.

The first objective requires the behavior in dichotomous networks, not previously examined over long periods of problem solving, to be simulated. The model used for this simulation should be considered as a vehicle which will be composed of, and cause existing propositions from learning theory, communication theory, and the CNE to interact.

There is evidence (McWhinney, 1964) that interaction or communication in this type of experimental setting has a large rational component. Furthermore, the variety of approaches taken by subjects to organize their group to perform effectively is small and, for the most part, well-defined. Therefore, according to the rationale for an individual learning process, the design philosophy to be adopted is to construct a program representing the details of the structural aspects for the networks and then separately to construct a simulation of the individual's behavior. The simulated subjects can then be placed in any desired network and runs can be set for any number of trials.

This research effort uses the individual member of the CNE as the basic unit of the system and attempts to develop a simulation model of the CNE by synthesizing data gathered by social scientists. The model is not constructed within any specific socio-psychological theory. The simulation, then, should be viewed as an algorithm which produces movement of a system consonant with empirical findings. (See Levin, 1970; Marshall, 1966; and Roby and Budrose, 1965.)

The second part of the study will involve experimentation on the model and generation and analysis of the data. Replications of experimental conditions will be made to accommodate the stochastic nature of the interacting variables. By constructing a model of the CNE which includes individual learning (in the form of feedback and reinforcement), this investigation is designed in the anticipation that the output or results of the model will resolve some of the previous inconsistent findings.

Two of Bavelas' original questions will be posed:

1. Will various networks reach an equal rate of productivity?

2. Why will some groups confronted with a task develop more or less rapidly in a productive fashion and in some cases fail to find systematic behavior to accomplish the task efficiently?

The first question is suggested by Burgess' work (1968) indicating the eventual attainment of a steady state for problem solving by two different networks (Circles and Wheels).[3] Other frequently used networks may also exhibit this type of behavior. If learning and reinforcement will produce this similar effect in other networks, the inconsistent results previously recorded may be explained by examination of the transitory state in which other experiments terminated (25 to 60 trials).

The basis for the second question stems from the indirect implication that individual learning rates are not the same for each network. Due to the complexity of stimuli (paired comparisons) and their combinations which must be performed by each member, the absorption rate of 'better channels' may account for differences in cumulative solutions[4] over time for each structure. Stated simply, it is not a matter of knowing the structure, but rather how many comparisons of behavior can be made and retained, so that an individual can identify those sequences which are most productive. It would appear that faced with more centralized CN these comparisons would be less complex, thereby explaining the rapid development of optimal or near-optimal productivity for Wheel nets.

If a learning model can produce long-term data similar to human subjects, it will then form a basis for theorizing on the crucial relationships within the CNE.

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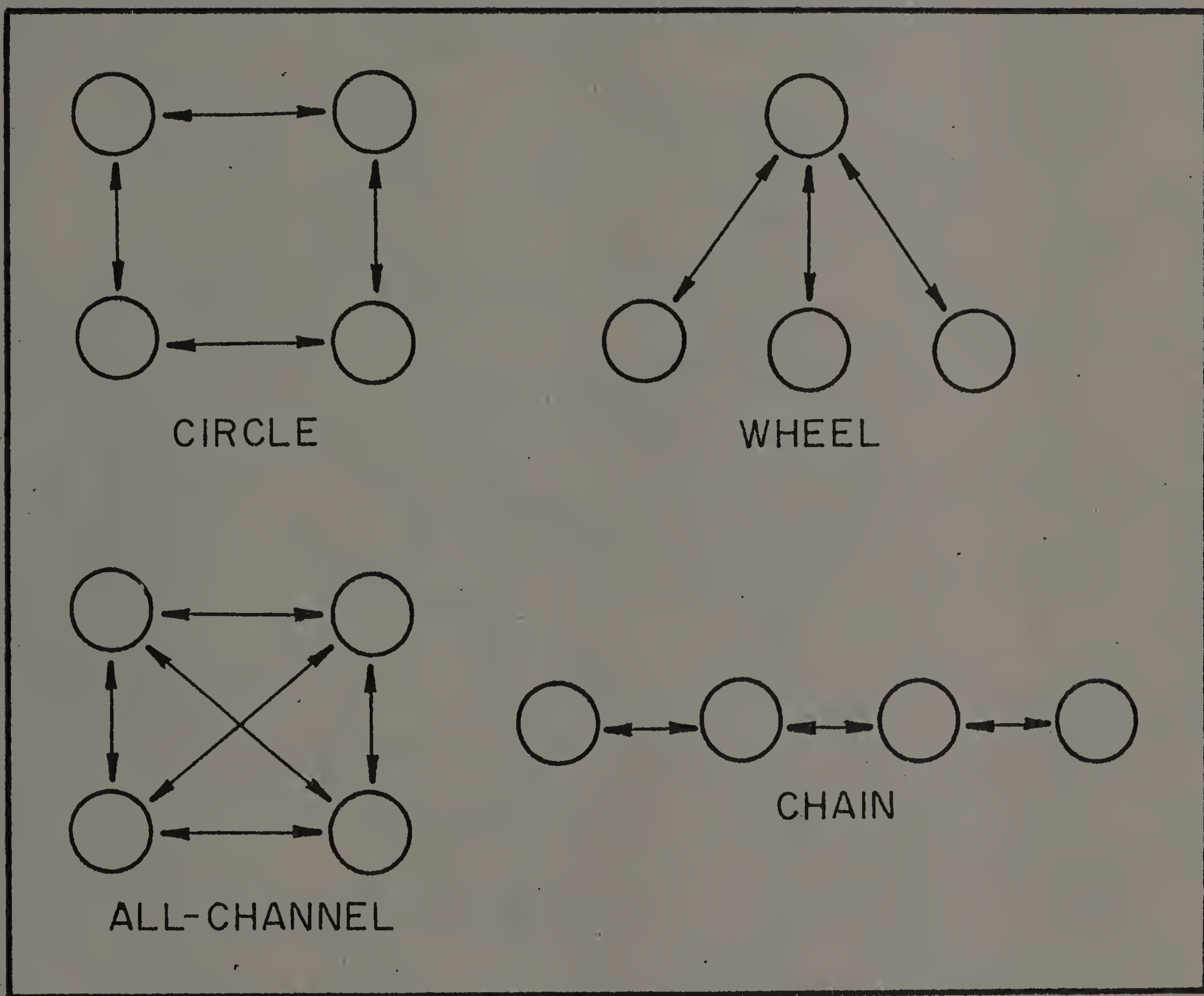
[3] See Figure 1-1 for a schematic explanation of all network discussed in this study.

[4] Cumulative solutions as used in this study refer to successful task completions which are solved up to a point in time.



COMMUNICATION NETWORKS

FIGURE I-I

The directions for this approach have been suggested by several researchers (Hare, 1962; Guetzkow & Dill, 1957; Stogdill, 1959; and McWhinney, 1964).

A brief description of the model is now presented which includes the major attributes of the individual members, the output and independent variables and the reasons for their selection.

A hypothetical network was constructed. The network consisted of four simulated members. Each member of the network was represented by a specific set of behavioral attributes. The behavioral attributes were identical for each member at the beginning of each simulated run. The value of these attributes was then modified internally and varied over time. These principal characteristics denoting each participant in the network were the value each placed upon:

(1) selection of a channel or another member to whom he wished to communicate

(2) selection of a message or type of communication desired.

Over time, both these attributes changed as a function of prior task success. A probabilistic reinforcement component was included which increased the liklihood of maintaining and readopting behaviors (selection of both channel and message) when they occurred, which reduced the number of communications required for group solution. Conversely, this likelihood was reduced when the adoption of behavior, or selections of channels or messages, was deleterious to the group's solution time.

The output, or dependent variable, under investigation is productivity. The job, or behavior, for each simulated member of the network was to send a sequence of messages to other participants in the network such that a solution was reached by everyone. Productivity, then, was measured by the solution rate, or time to solution, achieved by a network. Time units were recorded as the equivalent of the number of messages sent, as in the experiments by Christie, Luce and Macy (1952). This measure also permits an evaluation of accuracy for the networks.

The total number of messages, or time units, required to complete the group, or network, task constituted a trial. Within each trial a sequence of messages used by each member was recorded in his 'memory'. Learning and employing shorter sequences of messages constituted the primary work of each simulated subject.

In the CNE, which included consequences of feedback, there seems little doubt that feedback often improves performance--as was early demonstrated by Leavitt and Mueller (1951). Therefore feedback was included at the end of each trial by permitting comparisons of current behavior to past successes (shorter sequences) for each member. This procedure is representative of human behavior in these experiments Cohen (1962).

At the completion of each trial, the number of total messages (time units) was recorded. These data should indicate over time the transition states on the learning process. The independent variable, therefore, should have been but was not time, or time spent attempting to solve or complete the repetitive task of the CNE paradigm. It was decided to use cumulative solutions rather than time in this study since the crucial variable affecting task performance or productivity obviously is experience in solving tasks, rather than experience in simply being present in an experimental environment. The path of cumulative solutions achieved by the networks was selected as the independent variable for the simulation.

The functional relationship examined was: what effects are produced by cumulative solutions (as they occur through time) on the task-solution rate of a communication network.

The wide-spread use of a productivity measure in nearly all previous CNE studies suggested the need for comparing solution rates or productivity between various networks and to examine the results of long run learning effects of these solution rates between networks.

Data Collection. The second step in the research required collecting and assembling data from previous findings such that a mathematically logical model could be constructed. Model construction consisted of specifying the components of the process, and both their relationships and interrelationships. The prime data sources were experimental studies, a significant portion of which were in the CNE literature. Unfortunately, the quality of the data varied. The necessary mathematical relationships between variables which are required in a simulation were seldom developed in this literature. The qualitative data used, therefore, required some transformation into mathematical terms. Moreover, transformation of data for model construction poses some problems for model fidelity and may restrict interpretation. The components and their relationships are discussed in Chapter Three.

Computer Programming. The first stage of the model's construction was in prose. This determined the sequencing of events along with continual correction aligning elemental relationships. The model was factored into smaller modules, then diagramed into a flow chart. Each action which occurred in the model was placed in block form, with each block representing one computer demand. Prior to writing the program from the flow chart, its internal consistency was examined. Checking the model at both the prose and flow chart stages is a necessary strategy. If the fidelity of the model is examined only after the program becomes operational on the computer, logic and coding errors become difficult to correct. The computer program was written in Fortran IV on a CDC 3300 computer. After the coding process, the program was debugged by modules, or blocks, to ensure the accuracy of the logical flow. In summary, the construction of the computer program involved the following sequence:

(1) prose

(2) flow chart

(3) computer coding

(4) debugging.

Independent and Dependent Variables. The experiment included one independent variable, cumulative solutions over time, which was not varied by the experimenter. Rather, its effect on productivity or solution rate was analyzed for two different communication networks. The networks used for this analysis were:

(1) Circle network[5]

(2) All-Channel network

The dependent variable in this study was:

(1) Rate of solution for the CNE task

The analysis required that relationships between these variables be established for each network. Since no previous data existed for the time period over which cumulative solutions were permitted during the simulated runs, estimates of experimental error were generated by replicating the results for each network six times. Each

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5 Exposition and constraints regarding the operation of these networks will be discussed in Chapter Two.

simulation run can be regarded, then, as a single statistical observation.

Data Analysis. After the model was constructed, the experimentation was conducted. A least squares regression technique was used to examine the relationship between variables. Since simulation produces a set of time series, the analysis of such data presented its own unique set of problems. Many conventional statistical methods are difficult to apply because it can not be assumed that successive observations are statistically independent. A sample of data ordered in time is not the same as a random sample drawn from a population, and cannot be treated in the same fashion for analysis. In this study the regression technique was used to describe the functional relationship of productivity to cumulative solutions experience in one- and two-level hierarchical networks. Also, the purpose for experimentation is to evaluate the relationships of the variables through transition states in learning. Curvilinear analysis was required to describe the behavior of various networks in their solution rates over a continuous time period. Regression techniques are concerned primarily with the derivation of an equation that describes mathematically the manner in which the variables vary jointly, or covary. Examinations were made of these equations such that differences between networks could be described.

Validation and Experimentation. The final steps were the validation of the model and analysis of the simulated data. The verification, or validation, of models is, perhaps, still the most difficult methodological problem in the process of the computer simulation approach. `Van Horn (1968, p. 2) defines validation as, "the process of building an acceptable level of confidence that an inference about a simulated process is a correct or valid inference for the actual process." Validation is a problem.

In this study, the positive economics stage of the validation procedure required comparing the output from the simulation model of the communication network with the output of the Burgess (1968) laboratory experiments. Burgess conducted a study to determine the effects of long term practice in the CNE pardigm on the productivity and eventual attainment of a steady state[6] of performance for two communication networks, the Wheel and Circle. These networks permitted communication only between members as indicated by the direction of the arrows.

The Burgess long-term experiments provided a benchmark against which the results of this simulation were constrasted. His study included fifteen groups of twenty subjects. Each group was

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[6] A steady state was defined as the maintenance of a level of accomplishment or the maintenance of a given rate of increase in accomplishment. The use of this definition was also employed in this study.

composed of five four-man communication networks for a total of seventy-five networks. Each of the networks was required to complete 800 problems or tasks in the CNE paradigm. The reason for this many repetitions, contrary to previous studies which ran for only 25 to 60 repetitions, was Burgess' hypothesis that learning would occur in a longer time period which might narrow the difference in task solution rates between the above-mentioned networks. The concept of learning was adopted in his experiments by including both positive and negative reinforcements for individual behavior. By comparing task solution rates and attainment of steady state levels of productivity, Burgess was able to draw inferences between the two networks used in the study and other preceding his. The strategy selected in analyzing the data called for producing a time path for the task solution rate over an equivalent number of trials or cumulative solutions . The output of the simulation model required the same 800 completed tasks for comparison.

Even if the results are comparable between the Burgess and other studies, this does not imply that the inferences drawn for another network simulated by the model are valid. Agreement with the Burgess experiments, however, could contribute to the face validity of the model.

Another technique was used to partially validate the model. Recall that the analysis required a repetition of the simulated output of the networks. This replication, in conjunction with fitting the data to time series curves, provided an opportunity to test the model's reliability (reliability is defined as the ability of the model to produce consistent time paths for the output variable regardless of the sequence of pseudo-random numbers used to drive the model). This required comparing the functions produced by the original and replicated runs using standard statistical tests. The functions produced should be sufficiently similar to each other to assure equivalence.

In summary, validation is not an all-or-nothing proposition. Van Horn (1971) pointed out that the degree of confidence in the verification of the model is left to the subjective judgment of the researcher. To accomplish this, a multi-stage validation technique was followed including rationalism, empiricism, and positive economics.

Limitations. This study has limitations in three areas; the variables and networks examined, the existing empirical findings related to the process, and the degree of validation which could be achieved. First, only one independent variable, successful cumulative solutions over time, was examined in this study. Factors such as morale, leadership emergence, organizational sequences, and group style (cooperative versus competitive) were excluded from the networks. These factors obviously affect a real group's output variable, task solution rate. The absence of these factors imposes limits on generalizing from the findings. Additionally, only two four-man communication networks were investigated which limit inferences drawn about other communication structures.

Second, a review of the literature, especially in the communication networks area (Collins and Raven, 1969), revealed some major inconsistencies in both terminology and mathematical indices. It was, however, usually possible to locate several consistent studies and therefore the model's components were based on these studies. The two previous attempts to simulate communication networks (McWhinney, 1964 and Marshall, 1966) assisted in recognizing the limitations of employing data from only one or two empirical works. Further problems in estimating values for the model's components were encountered by the lack of appropriate mathematical relations which are necessary in simulation studies. The majority of the communication network literature only reports the effects of independent variables on dependent variables in a verbal manner with little mathematical explanation of processes. In every case, the verbal explanations were used to develop linear relationships between the variables in the model. No higher order relationships were established.

Inconsistencies of data and unclear functional relationships needed for the model detract some of its face-validity. Although this problem exists for many simulations, it is particularly acute in socio-psychological simulations.

Lastly, validation problems impose limitations on the study. To use the simulated system to make statements or draw inferences about the real system, the model must adequately represent the real system. The procedures that have been suggested are generally multi-stage verification processes which should support the model's fidelity. The comparison of time paths and functional relationships with the data compiled by Burgess (1968) is another attempt at partial validation. To the degree that validity can be established for one set of conditions produced by the model, caution must be exercised when establishing the virtue of other variations of the model. Essentially, then, these validation procedures are null tests. A model would be suspect if it failed these tests, but no strong statements can be made for a model which passes.

<u>Summary</u>. This study has two objectives. They are a refinement of the general hypothesis that learning and reinforcement may account for and explain differences in task productivity between the networks mentioned.

(1) Construction of a simulation model of a communication network.

(2) The testing of specific hypotheses regarding the effect of cumulative experience in task solving on the solution rates for selected communication networks.

A model of the communication network was constructed which builds upon both the communication network literature and group dynamics. The network consists of four-man groups. By using regression analysis techniques, the effects of task experience on task solution rate is examined. Finally, the results and conclusions from these analysis are presented.

In Chapter Two, an overview of the model is presented with an explanation of the paradigm used in CNE. A discussion of the model's elements, the related research and relationships developed are presented in Chapter Three. Chapter Four is the methodology section. The reasons for the use of regression analysis are offered. The results of the analysis and relationships of the output data are discussed in Chapter Five. The study is summarized and the conclusions are presented in Chapter Six.

CHAPTER II

AN OVERVIEW OF THE MODEL

Introduction

This chapter presents an overview of the model of the communication network experiment. Its purpose is to provide an integrating framework within which the relevant research presented in Chapter Three can be examined. First, the next section presents the paradigm, or task employed, in the networks and discusses its use in other experiments. Then, the behavior of the model is traced through time.

Nature of the Task. In the Bavelas' original experiment, subjects were seated about a circular table, separated by vertical partitions which prevented face-to-face contact. The center post to which the partitions were connected contained slots which could be opened and closed by the experimenter. This arrangement permitted the subjects to communicate, via written messages, only through these channels selected beforehand by the investigator. Some of the structures explored by Leavitt were the Circle, Wheel and Chain networks. See Figure 1-1. From a set of six symbols (asterisk, square, etc.) each subject was given a set of five symbols. The lists were constructed such that only one symbol appeared on all the subject's lists. The assigned task was to discover the common symbol, and then relay this information to every member of the network. Each such problem and its solution were considered a trial, and groups were run for several trials.

Although a number of similar tasks and variations have been employed in subsequent research, nearly all bear a resemblance to Bavelas-Leavitt task. All the members of the group must participate to complete the task, in that each possesses a vital portion of the solution and each is required to know the final answer.

After the initial experimentation, the popularity of the network paradigm among researchers resulted in some inconsistent findings. In an attempt to clarify some of the inconsistencies within the CNE findings on productivity, Burgess (1968) classified two types of tasks which had been used by researchers in this area. He labeled the above discussed first type the 'simple' problem and the second type 'complex' problem. The latter referred to a variety of arithmetic calculations.[1]

The complex problem required mathematical calculations by some or all of the network members. By classifying previous network

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[1] Complex problems are similar to the following: A company is moving from one building to another. It must move: (a) chairs, (b) desks, and (c) typewriters. How many trucks are needed to make the move in one trip? For a three member group, six items of information would be needed to solve the problem and these would be divided equally to all members. For example, the company owns 12 desks, 48 chairs and twelve typewriters and one truck load can take 12 typerwiters, or 3 desks, or 25 chairs.

experiments using this simple taxonomy,[2] Burgess (1968, p. 325) was able to remove some of the contradictions concerning which network was more productive for the different tasks. Table 2-1 is a compendium of these findings for the different tasks by Burgess (1965).

For the 'simple' task seven out of thirteen studies reported that the Wheel network produced the highest solution rate. The Wheel is a network in which organizational problems are kept to a minimum. All information is directed toward the individual occupying the central position. Typically, this individual, upon receiving the information provided by the others, solves the problems and sends answers to the network members. However, the All-Channel network for the simple task was found to produce the highest rate of productivity in three cases. The All-Channel network permits direct communication among all members. In three instances there were found to be no significant differences between these networks. Explanation of this seeming contradiction will be found in the conclusions drawn from this simulation study in Chapter Five. The present study employed the 'simple' Leavitt-type task.

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[2] To prevent confusion in terminology for these two tasks, simple problems are those of pattern recognition and complex problems are similar to those of resource allocation and/or linear programming problems.

TABLE 2-1

SYNOPSIS OF COMMUNICATION-NETWORK FINDINGS

Author	Date	Group size	Network solution rate (in descending order)	Task
Leavitt	1951	5	Wheel (fastest trial)	Simple
Heise and Miller	1951	3	All-channel: Wheel: Circle	Simple
			Wheel: All-channel: Circle	Complex
Hirota	1953	5	No significant difference	Simple
Shaw	1954a	4	No significant difference	Complex
Shaw	1954b	3	No significant difference	Complex
			No significant difference	Simple
Guetzkow and Simon	1955	5	Wheel: All-channel: Circle (stable nets-no signif. dif.)	Simple
Shaw	1956	4	All-channel: Wheel	Complex
Shaw and Rothschild	1956	4	All-channel: Wheel	Complex
Guetzkow and Dill	1957	5	All-channel: Circle	Simple
Shaw, Rothschild, and Strickland	1957	4	All-channel: Wheel	Complex
Shaw	1958	4	All-channel: Wheel	Complex
Mulder	1959	4	Wheel	Simple
Mulder	1960	4	No significant difference	Simple
			No significant difference	Complex
Mohanna and Argyle	1960	5	Wheel	Simple
Cohen, Bennis, and Wolken	1961	5	Wheel	Simple
Cohen, Bennis and Wolken	1962	5	Wheel	Simple
Lawson	1964a	4	(NR) All-channel, Wheel: Circle	Simple
			(R) Wheel, All-channel: Circle	
Lawson	1964b	4	(NR) All-channel, Circle: Wheel	Complex
			(R) All-channel, Circle: Wheel	

NR = nonreinforced; R = reinforced.

This table shows some of the differences in solution rates which have resulted from studies of a short duration.

General Discussion of the Model. In the following description, terms which should ordinarily be applied only to humans are used to describe the characteristics of a symbolic model of human behavior. This is done for convenience and clarity in presentation. Henceforth, the model's equivalent of a human subject will be called a "MAN". References to human subjects hereafter, will use the term "subjects" not "men". The capitalization of the word MAN is done to make it clear that it is the model which is under discussion, not some aspectof a human subject's behavior.

In experiments by Cohen (1962), Leavitt (1951), and Shaw (1954, 1958, 1961 and 1964), subjects sent messages at will until everyone signalled that he had the answer. The simulation program is not as flexible. Because of the sequential nature of the computer, sending messages proceeds as follows:

(1) Each MAN selects a message to send (or decides to wait).

(2) Each MAN chooses a permissible channel or other MAN to receive the message.

(3) The messages are sent; all information vectors and matrices are updated and such other changes as may be required are made.

The basic time unit in the simulation was that interval of time in which each MAN had an opportunity to send or request one message to or from another network member. Such an exchange of messages is called a round. A sequence of rounds ultimately leads to each MAN having the answer. Such a sequence is called a trial. The accomplishment of successive trials constitutes the primary activity of the model's MEN.

To proceed through these three choices the problem-solving behavior exhibited in the model was composed of four stages (Laughery and Gregg, 1962). They are:

1. searching
2. comparing
3. remembering
4. altering behaviors.

These actions are performed by the MEN and are outlined with this classification.

<u>Searching.</u> Searching procedures required a MAN to decide with whom he wished to communicate, and what the nature of that communication would be.

In experiments with human subjects, a group engaged in fifteen or more trials for the common-symbol problem (Leavitt, Cohen). Shaw's groups solving complex problems sometimes ran only a few trials. Cohen, Bennis and Wolkon (1962) found important changes in network activity to occur after trial fifteen, and in some cases, as late as the last few trials (60 trials). It is important to notice here that in this artificial structure of rounds within a trial, a uniform activity rate is imposed on the MEN. Subjects do not exhibit this uniformity except in some experiments by Christie (1954) in which it was arbitrarily imposed by the experimenter.

Human subjects evidence some degree of peculiar behavior during these experiments. They send jokes to each other, curse and draw pictures. Experiments which examined the content of messages (Guetzkow and Simon, 1955; Guetzkow and Dill, 1957; Cohen, 1962) found that on the whole messages could be classified in a fashion similar to Bales' (1968) interaction process analysis.

The model MEN have only four possible messages to send. These messages are:

(1) Data - a collection of symbols not understood to be the answer.

(2) Send me your data

(3) Send me the answer

(4) Waiting (this is not sent)[3]

This restricted set of messages was used for several reasons. In the experiments by Cohen (1962) all messages and scrap paper were collected and examined. His conclusions from the content analysis yielded the classifications used in the model. Marshall (1966) reported that it seemed as though subjects frequently did not respond appropriately, if at all to more complicated messages. Also, it often

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[3] Although the null act of waiting cannot be construed as a message, it will be referred to as such for the sake of clarity when discussing the possible actions of the MEN.

appeared that more complex messages did not have a great effect upon subject performance. He, too, suggested this classification of messages.

It is easily understood, and indeed most human subjects recognize, that the common-symbol problem can be carried out using the complement of each subject's four symbols. (The model uses four man groups, hence a pool of five symbols.) Using the complement symbol achieves a net gain in efficiency with no loss of accuracy. Cohen (1962) indicated that, on occasion, some groups would attempt to use this method. The model was constructed to operate in this fashion.

Each Man, then,. had two primary sets of probabilities (arranged in matrices) which described his propensities for selecting each type of message to each other MAN in the network. The first matrix contained the probabilities for selecting one of the four actions only. Mathematically this can be expressed as follows:

Let $P(A_{ij})$ = The probability of MAN j selecting action (message) i.

$i = 1, 2, 3, 4$

$j = 1, 2, 3, 4$

such that

$$\sum_{i=2}^{4} P(A_{ij}) = 1.0$$

The four possible messages were:

1. Data.

2. Requests for data.

3. Requests for the answer.

4. Waiting.

Relaying, or sending the answer, is not included in this set. Rules governing this behavior are explained below.

The second matrix described the network or channels available to each MAN to send these messages. This can be denoted mathematically as follows:

Let $P(C_{ij})$ = The probability of MAN j selecting channel i.

such that

$$\sum_{i=1}^{4} P(C_{ij}) = 1.0 \text{ for } j = 1, 2, 3, 4; \text{ where } P(C_{ij}) = 0.0 \text{ when } i = j$$ [4]

Therefore, a MAN can use, at most, three possible channels. In a network where MAN 2 could not communicate to MAN 4, the probabilities in MAN 2's vector would be:

for j = 2

$P(C_{1j}) = .5$

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[4] In both the above matrices, the diagnals were set equal to zero. Also the off-diagnals were not necessarily symmetrical.

$P(C_{2j}) = 0.$

$P(C_{3j}) = .5$

$P(C_{4j}) = 0.$[5]

This method permits the specification of any communication network.

Comparing. A MAN was required to compare his current behavioral choices (selection of channel and message) with recent actions of other members, as they may have placed expectations or demands upon him. These comparisons were made by evaluating the state of three matrices which are discussed below (ANS, N, D).

Prior to selecting either a message or a channel, a MAN had to be aware of his progress toward a solution. His choices could be modified as a consequence of experience in previous rounds. Other than the first round of every trial, three states of nature could limit the selections. A MAN had to determine whether:

(1) he had the answer

(2) data for answers had been requested of him and by whom

(3) the state of his information vector had changed during the last round.

First, if a MAN had received the complement symbol from every other network member, he had determined the answer. It was then convenient to represent each MAN's state of information during

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[5] In this example the channels are open in both directions. However this is not the case in other networks such as a Wheel.

a trial with a Boolean vector as follows: the vector contains a place for each MAN in the network and an extra place for the answer. When MAN j starts a problem, all vector positions are 0 (zero) except the jth, which is 1. The usual rules of Boolean operation govern subsequent acquisition of information -- as MAN j receives data from others, for example MAN k and MAN m the kth and mth places in the vector have their 0's replaced by 1's. Repetition of data received does not subsequently change the 1 to anything else. Whenever a data message is received, the receiver's information vector is updated and checked to see if all places but the last one are filled. If they are, then the last one is filled automatically and MAN has the answer. This is the equivalent to saying that a MAN always knows how to get the answer and does so when he has all the data. In fact, human subjects are not always so intelligent and self-reliant. One subject in Cohen's experiments frequently sent the data to his neighbor for a final decision, even though he himself had all the data required for determining the answer. The model does not permit this timidity. Whenever a MAN has all the information, he has the answer. In fact, when a MAN is requested to send the answer, he does so by sending, in effect, his information vector.

The elements of his information vector described mathematically as:

Let ANS_{ij} = Equals 1 if MAN j receives data from MAN i;
Equals 0 if MAN j does not receive data from MAN i.
where $i = 1, 2, 3, 4$
$j = 1, 2, 3, 4$
where $ANS_{ij} = 1$ when $i = j$

such that when

$$\sum_{i=1}^{4} ANS_{ij} = 4, \quad ANS_{5j} = 1$$

The interval between rounds serves for updating information vectors. A data message may contain only the 1's present in a MAN's vector at the beginning of a round. Data received by MAN j from MAN i during a round are not available for sending to MAN m in the same round. They may be sent the next round, though. Thus, the model confines message transfers during a round to previous messages only.

This Boolean vector is a simplified representation of subject performance, but corresponds to it very closely for subjects who were 'solvers'. The person or MAN who deduces the answer instead of having it sent to him. Many of these subjects kept exactly the information contained in the program's matrix. The simulation program tracks this activity and can display a list of 'solvers' at the end of a trial.

Another model provision for sending data was that whenever a

MAN sends data he sends all he has at the time. Even a casual observation of human subjects and their data messages bares the falsity of this provision, although in time subjects may have learned to behave in this fashion. To date, there has been insufficient empirical work necessary to adopt another provision. However, an evaluation of subsequent output indicated that this representation resulted in a reasonable correspondence with real-world behavior.

Referring to data from Cohen's experiments, the number of messages sent on the first trials was quite high. Some were as many as twenty-five, most were somewhat fewer. Actually for a four-man Circle network, the solution can be obtained by sending messages for three rounds. Some groups of subjects managed to attain this in later trials (as did the MEN). The model, however, was able to produce in the range of 18 to 23 rounds for the first trials. Although a visual comparison was not precise (between actual and simulated data) it did increase the confidence in the model's ability to represent the real process even with the imposed restrictions on message sending.

Once a MAN had determined the answer by examining his information vector, he was constrained to (1) sending only the answer through any available channel or (2) waiting. Initially this restriction was artificially imposed. Human subjects sometimes did not exhibit this behavior during the beginning of experimental trials. However, the MEN, similar to human subjects, learned after successive solutions that this behavior (waiting in the model, and other activities by subjects) did not improve the solution rate for the network. Consequently, this decision (sending the answer as soon as it was achieved) rule was adopted in a pattern as evidenced by human subjects.

The next modification in the searching and selecting procedure was the identification of requests. Two of the permissible messages were requests for data or for the answer. Either of these might require an appropriate response. To identify properly and attend to these requests, a set of vectors was constructed to indicate (1) which channel had made the request and (2) which request it was. At the beginning of each trial all the vector positions were set at zero. If MAN k asked for data from MAN j, the data vector of MAN j was incremented by 1 in the kth position. Each element in this matrix then, was increased by 1 for every request received and decreased by 1 when that request had been responded to. Mathematically this can be expressed as follows:

N_{nij} = The number of requests from MAN i, of MAN j,
for $j = 1, 2, 3, 4$
$i = 1, 2, 3, 4$

where $n = 1$ is a data request
$n = 2$ is an answer request

where $N_{nij} = 0.$ when $i = j$

This tracking procedure is, in fact, indicative of human subjects who kept a running account of these requests (Cohen, 1962). Thus, network members could recognize and respond to demands made upon them. Once a MAN wished to comply to these inquiries, then both his message and channel selection were constrained to the appropriate response and the required channel. The functional operation and decision rules involved in this process are discussed in Chapter Three.

To eliminate duplicate and extraneous messages a further constraint was incorporated. It would be possible for a MAN to repeat sending data incessantly through the same channel round after round without having any new symbols to impart. Man j could send data to Man k on successive rounds when his state of information had not changed. Therefore, a MAN probabilistically refrains from sending repetitious data of this form. This probability is decreased directly when this set of conditions recurs. A mathematical expression follows.

Let $P^t(D_{ij})$ = The probability of a data message sent from MAN j to MAN i during trial

V_r = A correction factor, a value less than 1, which is determined by the number of times these conditions have occurred. r denotes the number of repetitions for this event.

such that

$$P^t(D_{ij}) = (P^{t-1}(D_{ij}))\, V_r$$

This procedure may be inconsistent with the mental processes of human subjects. Although there is little experimental evidence to indicate the sequential nature of this process, it was adopted to reflect similar observable behavior in subjects.

Remembering. The "memory" of the MEN is imperfect. They do not remember what messages were sent or received from trial to trial. The results and actions for only the last round are stored in each MAN's memory. With regard to the memory of human subjects, initially a subject does not know what network connects him with others and even when he determines this does not exhibit behavior indicative of his knowing the best routing scheme for task success. What apparently occurs is that a subject will hypothesize an organizational scheme which appears appropriate and will adopt suitable behaviors. Clearly, the memory of human subjects in these experiments was far from precise. In one of Cohen's aberrant groups, one subject remarked that he was forced to work with mental defectives, when in fact, they were senior college students. The MEN are required to remember only the transactions of the latest round. This assumption is weak, at best; however, this is the minimal level of expectation derived from the experimental findings. It should be recalled that even with this restriction, MEN are able to remember exactly the requests which have been made because these are tracked from round to round.

Altering Behaviors. Changing behavior, in the S-R tradition, suggests some effects of learning. The incorporation of learning into the modus operandi of a MAN was suggested by Lanzetta and Roby (1957). Noting that individual learning in task-oriented groups was a function of both task conditions and structural demands, they indicated that an individual would learn to adapt in the most efficient manner (for him) to the task and structure.

The presence of feedback and reinforcement is a necessary condition for the facilitation of learning. A group's performance without appropriate (i. e. differential) feedback is insufficient to achieve or maintain group proficiency. Also, practice alone could lead to a decrement in group performance as a result of absence of reinforcement, (Glaser and Klaus, 1966). Even for very high levels of initial performance, some form of differential feedback must be used to prevent any deterioration.

In most CNE, reinforcement was provided by permitting all subjects to know when the trial or task had been completed, or after some number of messages had been transmitted. Providing feedback is included in the Leavitt task, but had not been clearly or precisely defined until Egerman (1966) stated that what has been termed communication channel and what may be called feedback channel are quite similar. Therefore, communication channels permit appropriate feedback for two network members when these channels are open in both directions. Thus, Bavelas (1950) supported by Leavitt (1951) and Heise and Miller (1951) soon recognized that networks with different attendant communication channels do affect network performance differently. However, these early studies had little to say in the way of a priori predictions of performance as a function of structure. At least the predictions were not even based upon learning-theoretic concepts which would permit the transfer of predictions from one network to another. Thus, even though communication channels and feedback channels may have been synonymous, not until Lawson (1964) and Burgess (1968) elucidated this point could this study have included an individual learning approach to a group's performance in the CNE.

The adaption of an individual learning approach was predicated upon the recurrent finding of independent rates of learning for individuals in task groups. In this regard, Lanzetta and Roby (1957) have noted that the rate of change in communication was independent of task demands.

The principles of learning employed in the model are loosely constructed upon Thorndike's "law of effect" (Hall, 1963, p. 59), a reinforcement theory in the connectionist tradition. The physical arrangement of the CNE isolates the network members such that both reinforcement and feedback must be channeled through one's communication links, if at all. Therefore, the type of learning adopted by each MAN was trial and error, instrumental conditioning or operant learning (Lawson, 1964).

When a trial is completed the model provides for a MAN to compare the number of rounds for the previous trial (PT) to the number of rounds for the current trial (CT). When PT = CT, the types of messages or channels used are recognized to be no more effective than any combination or permutation of messages and channels which were employed during the previous trial. In a loose sense a MAN realizes that his actions did not permit the number of rounds to decrease relative to the last trial. Therefore, his probabilities for selecting either a message or channel would not be positively reinforced or incremented. Reinforcement refers to the occurrance of a certain class of events in the proper relation to the to-be-learned response. The proper relation is that which tends to increase the probability of the response recurring. This formation is consistent with the author's concept of changes in message and channel selections, ΔA_{ij} and ΔC_{ij}. Whenever CT > PT, a MAN realized his actions were detrimental to the group's performance and again his behavior would not be reinforced. However, if one or more MEN employed a sequence of both messages and/or channels such that CT < PT, each MAN would immediately recognize that his efforts were more efficient than those of the previous trial. The predominant choices of messages and channels selected during this trial were then reinforced by incrementing the associated probabilities. Negative reinforcement was loosely applied by corresponding decreases in the probabilities associated with the less frequent, or unused, behaviors. Recall that in the two matrices used for the selection of both messages and channels, the summation of probabilities for each MAN was 1.0. Thus, these probability changes were shifted satisfying this equality. Symbolically, learning is expressed as follows:

An instance of learning by MAN j, only when PT - CT < 0.

$$\Delta P(A_{ij}) = P^{t}(A_{ij}) - P^{t-1}(A_{ij}), \quad \text{where } t = \text{present trial},\ i = 1, 2, 3, 4,\ j = 1, 2, 3, 4$$

$$\Delta P(C_{ij}) = P^{t}(C_{ij}) - P^{t-1}(C_{ij})$$

It should be noted that a MAN could only evaluate his transactions as in the laboratory setting. Here a subject was not aware of what all the members are doing. Thus, it is quite possible for a MAN to use combinations of messages and/or channels which might inhibit efficiency; yet, if CT < PT, he would be reinforced for this inhibitory behavior. Improvement of the solution rate, or efficiency of performance, then becomes a function of individual learning rates. Clearly, while some MEN may be reinforced for 'good' behavior, others may be reinforced for 'bad' behavior. To achieve long-term increases in efficiency, or rates for solution, each network member must eventually increase his probability of sending data messages and decrease the probability of other choices of behavior.

Basic Model Assumptions. In most analytical models, the assumptions are clearly stated. Simulation models tend to mask their assumptions. Therefore, the model's salient assumptions are presented.

1. The simulated subjects (MEN) are equal in their ability to perform the task. There is no prior experience.

2. Initial rates for sending messages and selecting communication channels are equal for all participants.

3. Learning does not occur at the same rate for all the participants.

4. No noise exists in the model's system; only communication relevant to the task is permitted.

5. The task is understood by all simulated subjects.

6. Each MAN works independently (as explained in the paradigm).

7. All current information is transmitted whenever a data message is sent.

8. Learning achieved by each simulated subject is measured by the difference between his present probability distributions for both message and channel selections and the initial set of distributions.

9. Learning and changing sets of behavior is permitted only at the end of a trial.

10. The degree of skill in the task accomplished by all the network members is measured by their rate of problem solution.

These assumptions define the process, yet at the same time, limit the inferences which can be drawn from the model.

The major features of the model, then, are:

1. A set of messages and channels which

   (a) lead to a solution of the problem.

   (b) influence behavior patterns.

2. A set of rules which

   (a) provided for probabilistic changes of message and channel selection.

   (b) permit non-optimal performance but require logical consistency in problem solution.

   (c) identify 'good' behavior and tend to have it repeated.

   (d) allow certain kinds of sensible behavior to develop over the course of a number of trials by 'recognizing' both desirable and undesirable modes of behavior.

3. A set of initial program parameters which are altered during the course of the simulation.

The sequence of the model. Examining the process of the model's operation from the computer's point of view, the nature of each simulated run can be subdivided into eight sequential steps. These steps are related to behavior by the categories listed in parentheses.

1. initialize parameters

2. generate selection rates (searching)

3. initiate task process

4. determine progress for network members (comparing, remembering)

5. evaluate task productivity

6. compute probability changes for selection rates (altering behaviors)

7. output dependent variable

8. return to step 2.

The last seven steps are repeated for as many times as desired. For this study, 800 repetitions were conducted for each run as explained above.

Summary. This chapter presents an overview of the computer simulation model.

Four simulated subjects comprise the experimental networks in the model. Initially each simulated subject is assigned probabilities to initiate messages and channels. Over time these rates of communication will improve as a consequence of feedback (Leavitt and Mueller, 1951); therefore, reinforcement is provided at the end of a trial by permitting comparisons to be made of current behavior to past successes. This procedure is representative of human behavior in these experiments (Cohen, 1964).

CHAPTER III

THE MODEL

Introduction

This chapter presents a detailed discussion of the simulation model's elements and interrelationships. The construction of many interrelationships was predicated upon the judgement of McWhinney (1964) and Burgess (1968, p. 331, p. 334) that interactions in the CNE setting have a large rational component. Furthermore, they indicated that the variety of approaches taken by subjects to organize their groups to perform efficiently is small and, for the most part, well defined. The MEN operated rationally, in that only the available paths at decision points could be selected.

To facilitate the presentation of the information processing procedure, a series of charts is provided. In a loose sense, they are flow diagrams of the searching, comparing, remembering and altering of behaviors performed by the MEN. The use of a programming language required specifications of these procedures in terms of subroutines, matrices, loops etc. which do not lend themselves to fluent explanations of behaviors. Therefore, the schematic representations and their explanation are presented in more common language. This casual treatment is not intended to mask or rationalize any assumptions or relationships. Rather, the stages and protocols are traced, the reasons for their use and outcomes and change mechanisms are explicitly stated.

Basic Model Process. Figure 3-1 is a presentation of the basic model processes. Each major stage is represented by a node or box.

Although the choices and decisions made by each network participant are relatively straightforward, the progression of behaviors to reach these points is not. The instances of switching and parallel operations may be more clearly understood by reducing each basic node into its components with a further diagram and exposition thereof.

Box 1

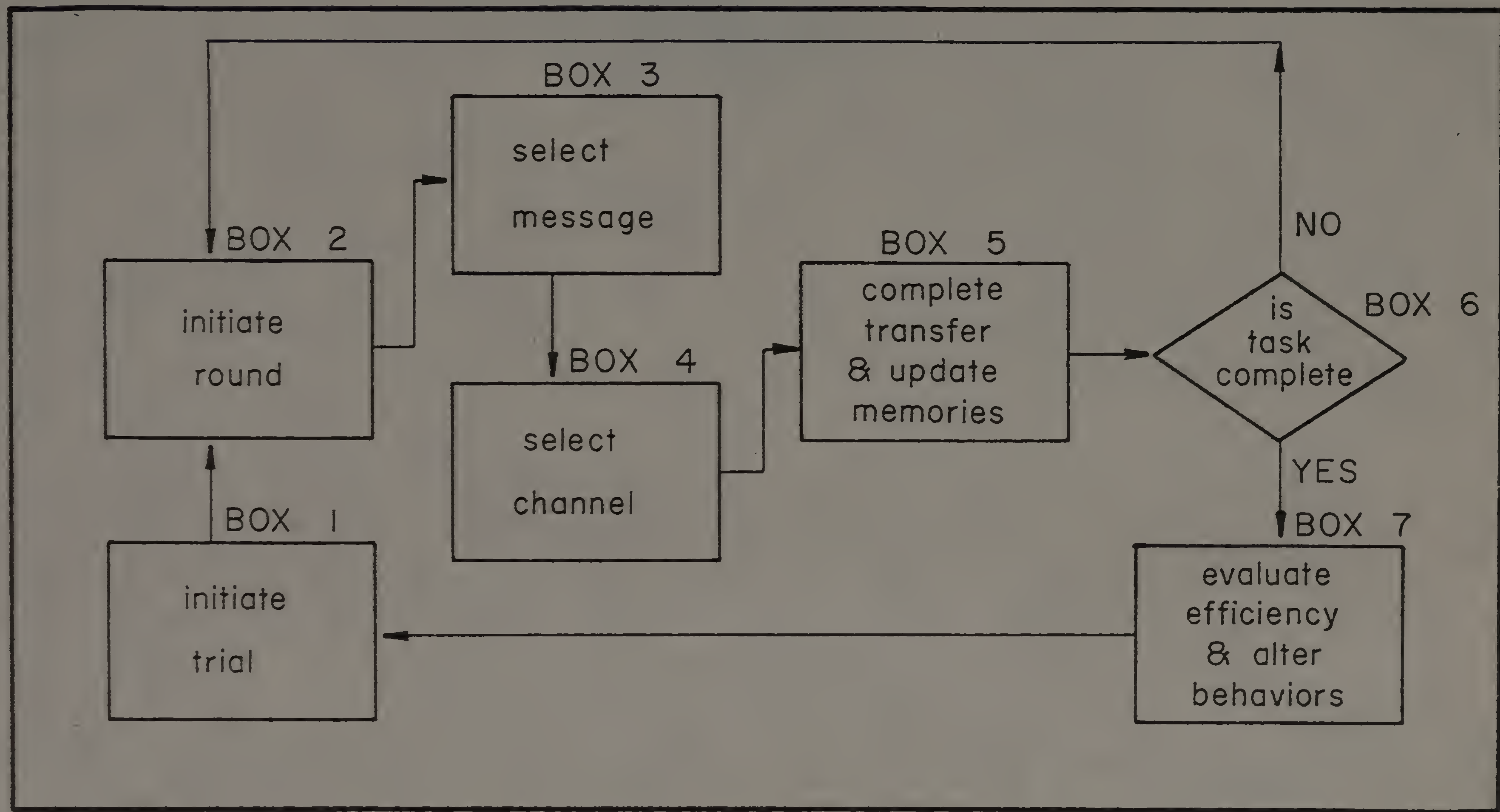
Trial Initiation

The task of each trial is independent from those previously accomplished. Being well-established in the paradigm, all previous experience was embodied only in the probabilistic selections for messages and channels, and all other decision paths remained open.

Box 2

Round Initiation

The beginning of a trial is initiated by a round. When the problem is solved and each MAN has the answer, the trial terminates. Until then, rounds consist of each MAN sending a message through a channel. To determine the rate of solution, the number of rounds



BASIC MODEL PROCESS

FIGURE 3-1

per trial was obtained as a measure of output. The constraint of sending simultaneous messages prohibited differential time units to be accumulated for every MAN--hence, the equivalence of time units to rounds.

Box 3

Message Selection

Four messages were employed in the information distribution process. They were

(1) transmittal of data.

(2) requests for data.

(3) requests for answers.

(4) waiting.

A discussion of input parameters for probabilistic selection of these messages is presented, followed by a delineation of the conditions which might attenuate this selection.

Without *a priori* knowledge, it is a reasonable practice in simulation models to set input parameters for choices of behavior equally. Descriptive indications of these behaviors are, however, present in the group problem solving literature. Shelly and Gilchrist (1958) studied this phenomenon in four man groups in Wheel and All-Channel networks. They reported that in these groups far more messages were sent than were necessary during the initial stages of the experiments. Kelly and Thibaut (1971) observed that these groups were handicapped by an inability to organize their information into profitable patterns. Subjects would forget to send crucial items of information, and much time was wasted in information-seeking and other behaviors, activities unnecessary in optimally organized groups. Similar observations are reflected by Cohen (1964). His content analysis of messages indicated a less frequent occurrence of data messages than any other type. Also, Lanzetta and Roby (1957, p. 57) pointed out that a

> . . . major problem faced by problem solving groups is not simply one of transmitting, but of phasing messages.

They explained further, that when each member has a primary source of information required for the task solution, initial solutions were replete with errors. This may have been due to fewer transfers of information.

Consistent with this evidence, the initial probabilities were set as indicated in Table 3-1.

TABLE 3-1

INITIAL PROBABILITIES FOR MESSAGE SELECTION

Message	Probability
Transmittal of data	0.10
Requests for data	0.30
Requests for answer	0.30
Waiting	0.30
	1.00

These input parameters reflect the inclination and propensity of subjects in group problem-solving activities to initially send fewer data messages and generate a number of communications which do not substantially contribute to optimal efficiency.

These initial probabilities are not consonant with Bales' findings reported in his Interaction Process Analysis scheme. However, his classification scheme might be open for interpretation when applied to this paradigm.

The first major decision made in the process was the selection of a message. Four factors could limit this direct choice. Whether a MAN had

(1) an answer.

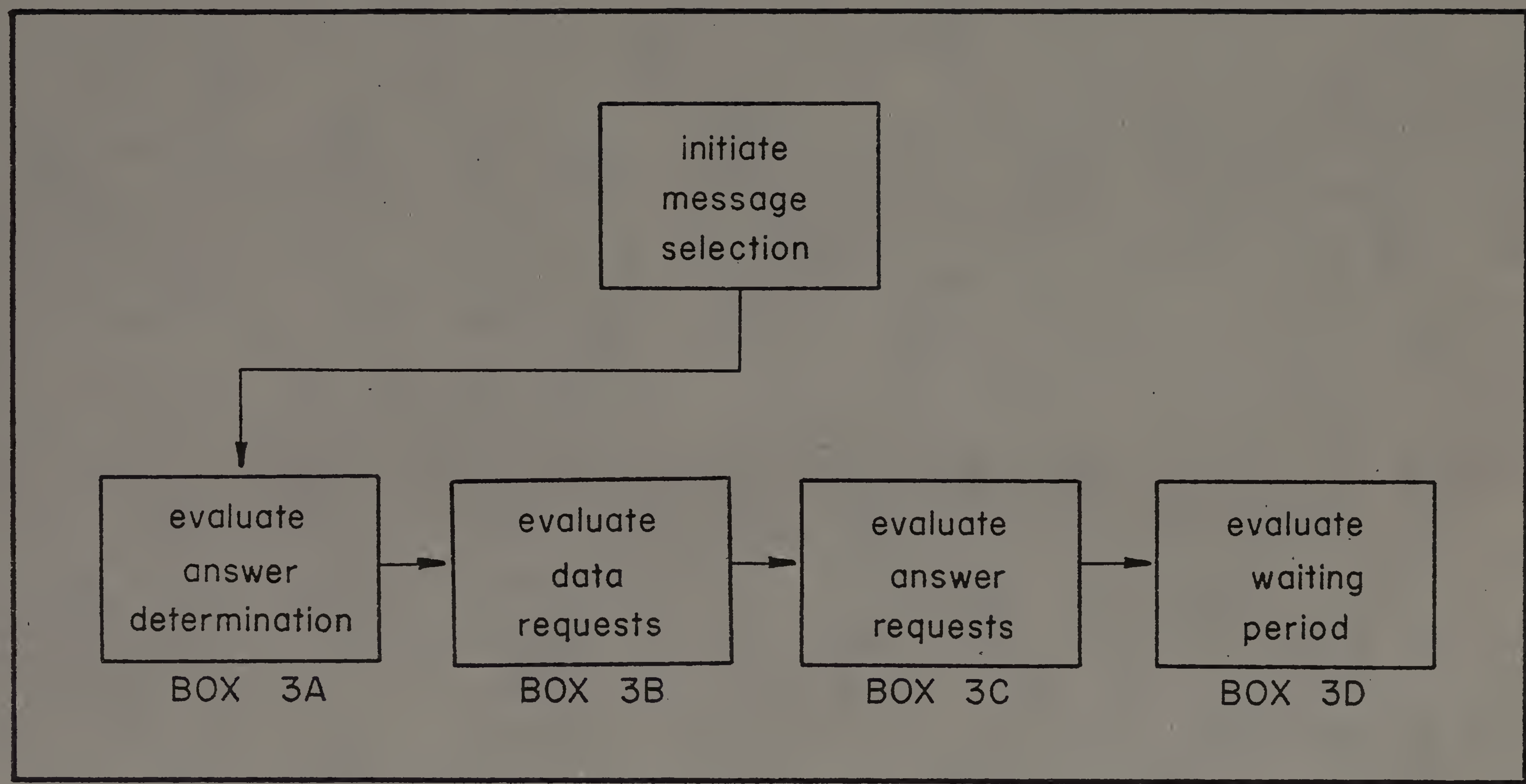
(2) any requests outstanding for data.

(3) any requests outstanding for an answer.

(4) waited during previous rounds.

A schematic of Box 3 is further delineated in Figure 3-2.

Box 3A Answer Determination. Consistent with the assumption concerning rational behavior, once an answer was compiled by a MAN he was constrained to sending it in place of extraneous information. Although some experimental evidence mentioned in Chapter Two indicates this may not always be true of subject behavior, this is the exception rather than the rule. For MAN j to send or transfer the answer to MAN i all the elements in MAN j's answer vectors



BOX 3: MESSAGE SELECTION

FIGURE 3-2

ANS_j, replaced all the elements in MAN i's answer vector. To search and compare for this condition, a MAN had to

(1) evaluate his state of information.

(2) identify which MAN needed an answer.

(3) check for answer requests.

The sequential process is outlined in Figure 3-3.

Box 3A1 State of Information. Recall the operation of vector ANS_{ij}. When $ANS_{5j} = 1$, the answer was available to MAN j, he proceeded to Box 3A2. If not, he moved on to identifying requests (Box 3B).

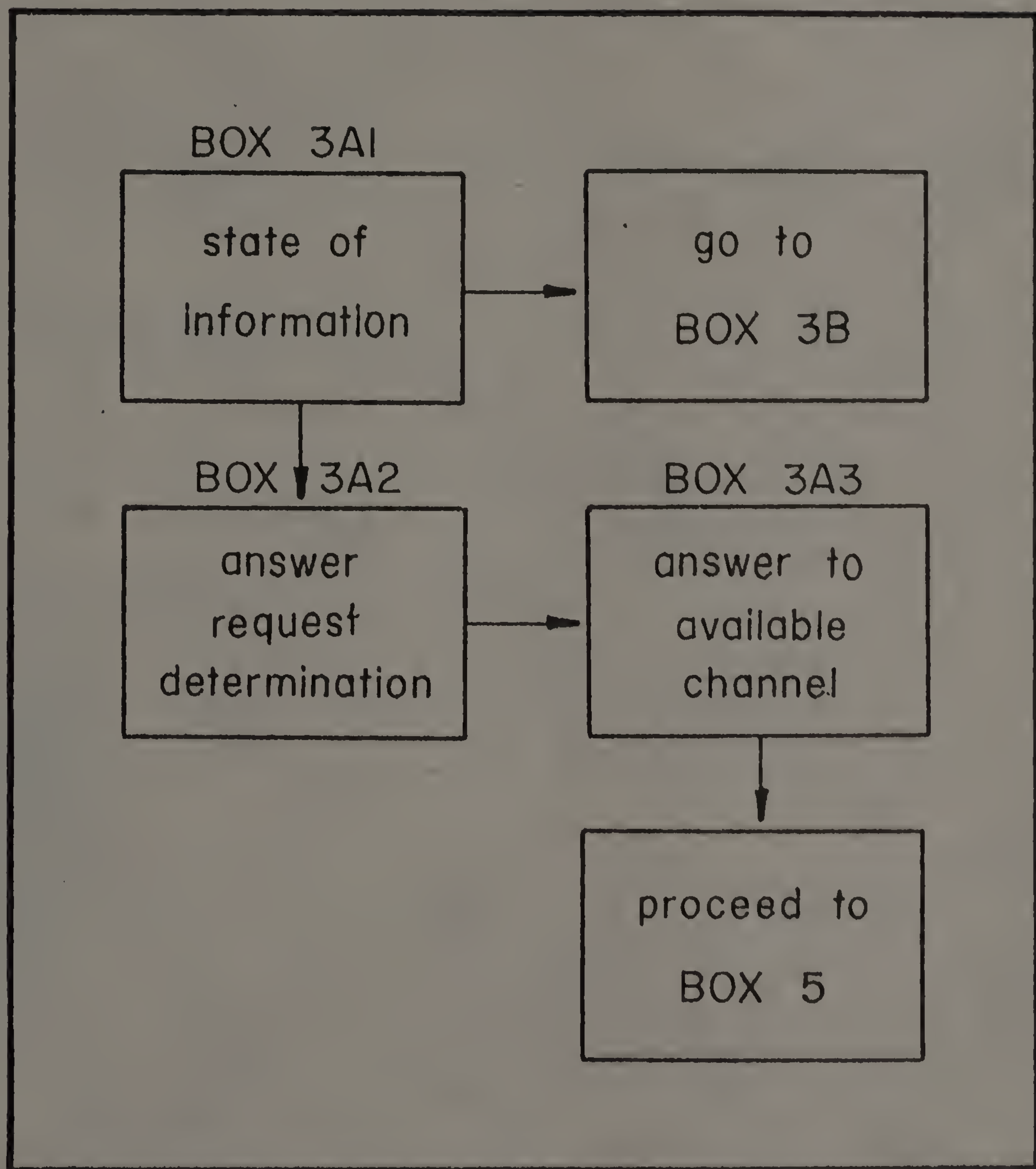
Box 3A2 Answer Request Determination. By evaluating N_{2ij}, a MAN could identify

(1) which i's had requested an answer.

(2) how many answer requests had been made by each i.

See the next page for a summary of symbolic expressions used in this chapter. If there were no requests for answers, a MAN would search for a possible channel through which to send his answers (Box 3A3). To determine through which channel a response to an answer request would be made, it is necessary to review two behavioral processes. Interaction rates are discussed now in general terms with more specific instances applied in Box 3. Response to Request rates are discussed in a similar fashion above.

Interaction Rates. Interaction rates are a major component



BOX 3A: ANSWER DETERMINATION

FIGURE 3-3

Summary of mathematical symbolism used in Chapter Three

1. ANS_{ij} = problem solution received by MAN j from MAN i.

2. N_{nij} = response n requested by MAN i of MAN j.

3. $P(C_{ij})$ = probability that MAN j will select channel i.

4. $P(A_{ij})$ = probability that MAN j will select message i.

5. KNO_{ij} = channels i which remain available to MAN j for transmitting an answer.

6. LST_{ij} = data sent from MAN j to MAN i during the last round.

7. $P(RS_{nj})$ = probability that MAN j will respond to request n.

8. KWA_{j} = the number of successive rounds MAN j did not send a message or waited.

9. V_{r} = a correction factor for selection of a channel when data was sent r times during a trial.

10. SN_{mij} = total of messages m sent to MAN j from MAN i.

11. RC_{mij} = total of messages m received by MAN j from MAN i.

12. DAT_{ij} = number of data messages sent by MAN j to MAN i during one trial.

13. $CUMSN_{mij}$ = cumulative total over all trials for SN_{mij}.

14. $CUMRC_{mij}$ = cumulative total over all trials for RC_{mij}.

of the model. They are used in a number of decisions where choices of channels are required (Boxes 3A3, 3B5, 3C5, 5A and 7C). The foundation for employing interaction rates is presented at this initial encounter. Demands for information can be placed upon a network member from others simultaneously. To establish priorities for reaction, exchange theory (Thibaut and Kelley, 1959) appeared appropriate.

The theory assumes that the existence of the group is based solely upon the participation and satisfaction of individuals within the group. Therefore, the analysis of group processes must be in terms of the adjustments that individuals make in attempting to solve their problems of interdependency. It is not too difficult to see that this view leads almost inevitably to the adoption of a reinforcement orientation. Thus, when an exchange of communication is somehow satisfying, the probability of further exchanges is reinforced between those participating. Thibaut and Kelley limited their analysis to a dyad, which is also considered the relationship between subjects in the CNE.

Two key concepts in exchange theory important to this study are interpersonal relationships and interaction. They are interdependent and can be defined together. The central feature of interaction is the interpersonal relationship, and two persons are said to have formed a relationship if they interact on several occasions. Interaction may be defined, as suggested by Thibaut and Kelley:

> By interaction is meant that they (dyad) emit behavior in each other's presence, they create products for each other, or they communicate with each other. In every case that we could identify as an instance of interaction, there is at least the possibility that the actions of each person affect the other (p. 10).

This process is included in the model; interaction is selective both as regards to who interacts with whom and what behavior sequences are enacted. This conception is much like input-output analysis. The consequences of interaction (outcomes) are described in terms of rewards and costs. Reward refers to those aspects which the individual finds gratifying or satisfying.

> The provision whereby a drive is reduced or a need fulfilled constitutes a reward (Thibaut and Kelley, 1959, p. 12).

If there is a positive balance between rewards and costs of an action, each new experience will lead to a modification of the interaction rate. (Similar to the suggestion by Thibaut and Kelley, the model permitted an increment for decrement from one interaction to be negligible.)

When a choice of channels needs to be made, the concept of "comparison level" is used. Thibaut and Kelley's comparison level (CL) is a loose standard against which an individual evaluates the attractiveness of an interpersonal relationship, or how satisfactory it was. In the model, whenever communications between two MEN have been rewarding (increased the solution rate), the attractiveness of using this channel is incremented. Therefore, the CL or selection of a channel is a direct function of which channel was most rewarding during past experience.

In summary, this analysis of group interaction can be used to predict the course of interaction if one can identify the rewards and costs in the situation. Thibaut and Kelley proposed that an individual generally repeats a rewarded response, but does not repeat a costly response. Therefore, in the model, whenever equally competing demands for information are placed upon a MAN, the response channel selected was that which had achieved the highest interaction rate. This concept is consistent with other formulations of this process (Sherif and Hovland, 1961; Homans, 1961; Helson, 1948; and Tresselt, 1947).

If only one answer request was present in N_{2ij}, that channel was selected. When more than one answer request was present, a comparison of $P(C_{ij})$ was made to isolate the highest interaction rate. A response was then made through that channel. In the case of equal rates of communication, conformity to expectations was applied.

A request may be viewed as a form of pressure. Pressures and expectations are created when a request is made, and are readily perceived because the transmission of these expectations are made very explicit in the communication process. Kiesler (1969) noted that when individuals are committed to each other because of situational factors (e.g., CNE) they will want future interaction to be as smooth as possible. In accordance with these expectations, Kiesler stated that a person will conform (with a response) so that the groups' goal will be achieved and/or the next interaction of this type will be rewarding.

Kiesler, Kiesler and Pallak (1967) report in an analogous situation that improvement in task efficiency requires group members to conform to informational expectations if they wish to be liked.

Therefore the tendency to conform to these expectations was increased as perceived pressures and expectations increased. Or as in the model's application, the greater the number of messages from MAN i, the greater the tendency to respond to MAN i. Therefore, whoever exerted the most pressure, in the form of requests, was most likely to receive the response. In the case of equally distributed interaction rates the highest value for N_{2ij} determined the response channel. The result of an answer response, at this point, was elimination and reduction to zero of any value in the corresponding or appropriate N_{2ij}. These three cases are summarized as follows:

(1) only one answer request

When only one answer request has been made of MAN j from all other network members, MAN j will act upon that request which is identified by the appropriate $N_{2ij} = 1$.

(2) answer requests from more than one network member

When answer requests have been made by more than one network member to MAN j, he selects the request from that MAN with whom he has the highest interaction rate to act upon.

(3) no highest interaction rate

When there is no highest interaction rate between MAN j and the other network members who have made an answer request to MAN j, the tie(s) are broken by a random selection.

Box 3A3 Answer to Available Channel. With no answer requests outstanding, the two options remaining are (1) to find an available channel or (2) wait for the next trial. The choice of a channel is dependent upon

(1) The channels through which answers had previously been sent.

(2) The channels from which answers had been received.

(3) Any remaining possible channels.

The selection of a previously used channel to send the answer was prohibited. The resultant endless repetition which would be produced by these behaviors is neither representative of human subject behavior nor permitting of solutions within reasonable time periods. Unless this restriction had been imposed, task solution rates could have been of indeterminate length at any time in the simulated runs.

Another decision rule to prevent repetitious messages was to prohibit answers to be transmitted through a channel from which the answer had come. A rational person would not return the solution to the source from which it had come. Conceivably, rather than deduce the answer, it could have been conveyed to a network member. Again, human subject behavior indicates a preponderance of evidence that returning the answer is redundant, does not increase the solution rate, and therefore occurs infrequently. Toward the end of a series of trials, this behavior was not present at all.

After an assessment was made for the two decision rules mentioned above, one or more channels could still be available. The selection would then be dependent upon the highest interaction rate of these remaining channels.

Once a MAN had sent answers through every channel permitted by the network, he ceased sending messages and waited for the next trial. Such behavior has not been systematically recorded and there is no evidence to support this contention other than a claim for rational behavior.

To test for these decision rules, a matrix was created to identify the transmittal of answers through his channel during a trial. This is mathematically expressed as follows:

Let KNO_{ij} = an element of the matrix denoting channels from MAN j to MAN i.

where j = 1, 2, 3, 4
i = 1, 2, 3, 4

where the diagnals = 1.0 and every element in the matrix which corresponds to a channel closed to communication for each network member is also set at 1.0. An open channel is identified where $KNO_{ij} = 0$.

The outcome of transferring an answer from MAN j to MAN i was to increment the appropriate $KNO_{ij} = 1$, to indicate to MAN j that he had used this channel to send the answer. Additionally, KNO_{ji} was set = KNO_{ij} so that when MAN j wished to send an answer during the next round, he would send it neither back to the member from which he received the answer nor to the member to whom he had already sent it. When all possible channels had been used such that

$\sum_{i=1}^{4} KNO_{ij} = 4.0$, MAN j would wait for the next trial.

Box 3B Data Requests. When a MAN does not have the answer, he proceeds to examine the results of the last round to identify requests for data. If they are present in N_{1ij}, several decisions must be made. These choices are embodied in Figure 3-4.

Box 3B1 No Requests. In the case where no data requests have been made, $N_{1ij} = 0$. for all N_{1ij}. Man j continues to Box 3C.

Box 3B2 Determine Source of Requests. In a fashion similar to Box 3A2, a MAN must determine

(1) source of requests from all i's.

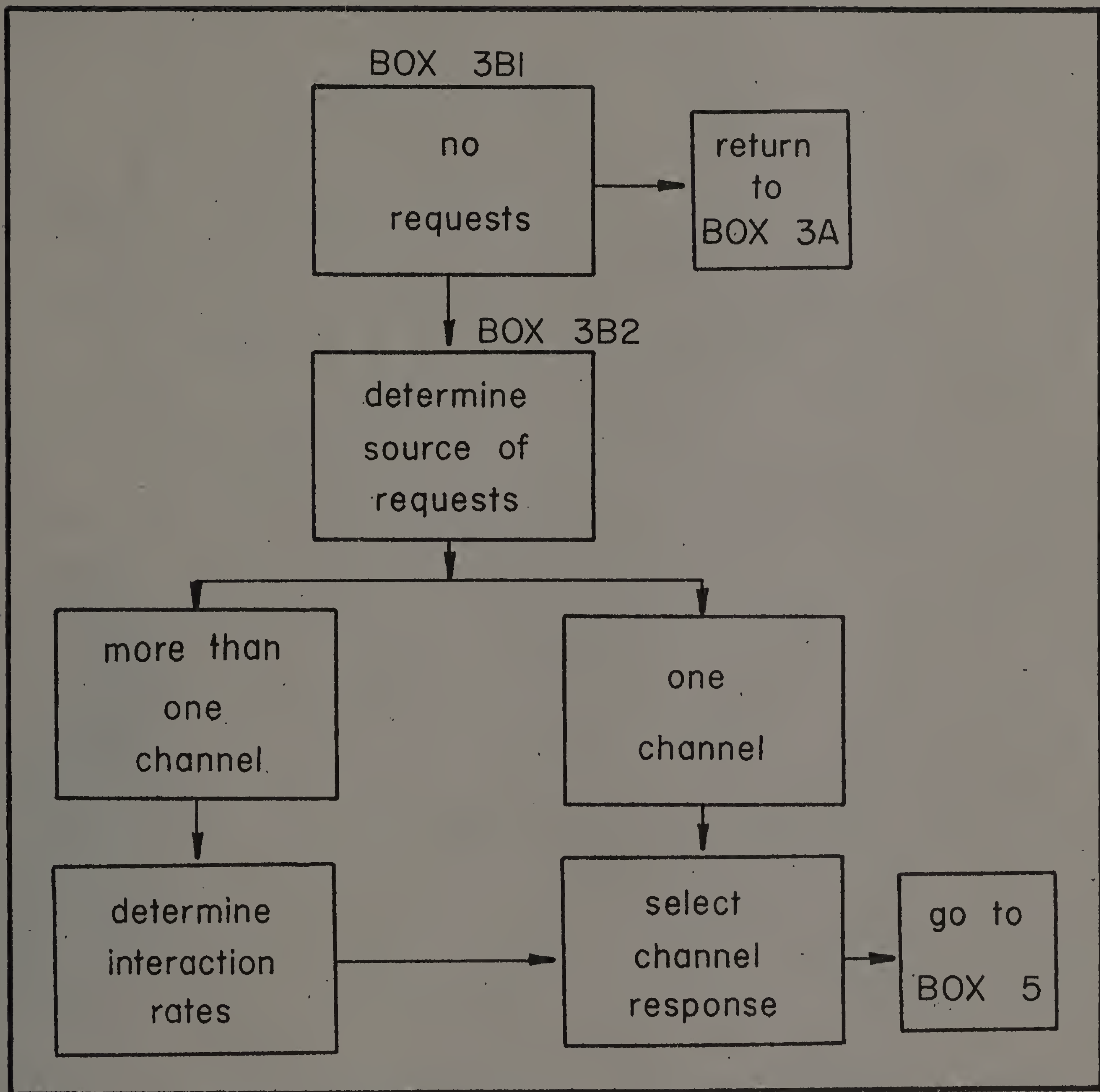
(2) number of requests for all i's.

(3) appropriate interaction rates of i's.

The mathematical symbolism is identical in this instance, except the substituting N_{1ij} for N_{2ij}.

There is one further constraint in the search for data requests. It is conceivable that MAN j sent his data to MAN j sent his data to MAN i during the last round. Since then he may or may not have received additional data. If no new data could be added to that which he had last round, a response through the same channel to MAN i would, in effect, be repetitive and not warranted. Therefore, once a channel was selected for a response, an assessment was made, first as to data sent last round, and next, as to the state of information vis-a-vis the last round.

The first comparison was made by examining a matrix which identified data sent from MAN j to MAN i during the last round. When this value was zero, no data had been sent. In the case where



BOX 3B: DATA REQUESTS

FIGURE 3-4

this value was positive, a further comparison was made on the current state of information. To represent this first comparison mathematically:

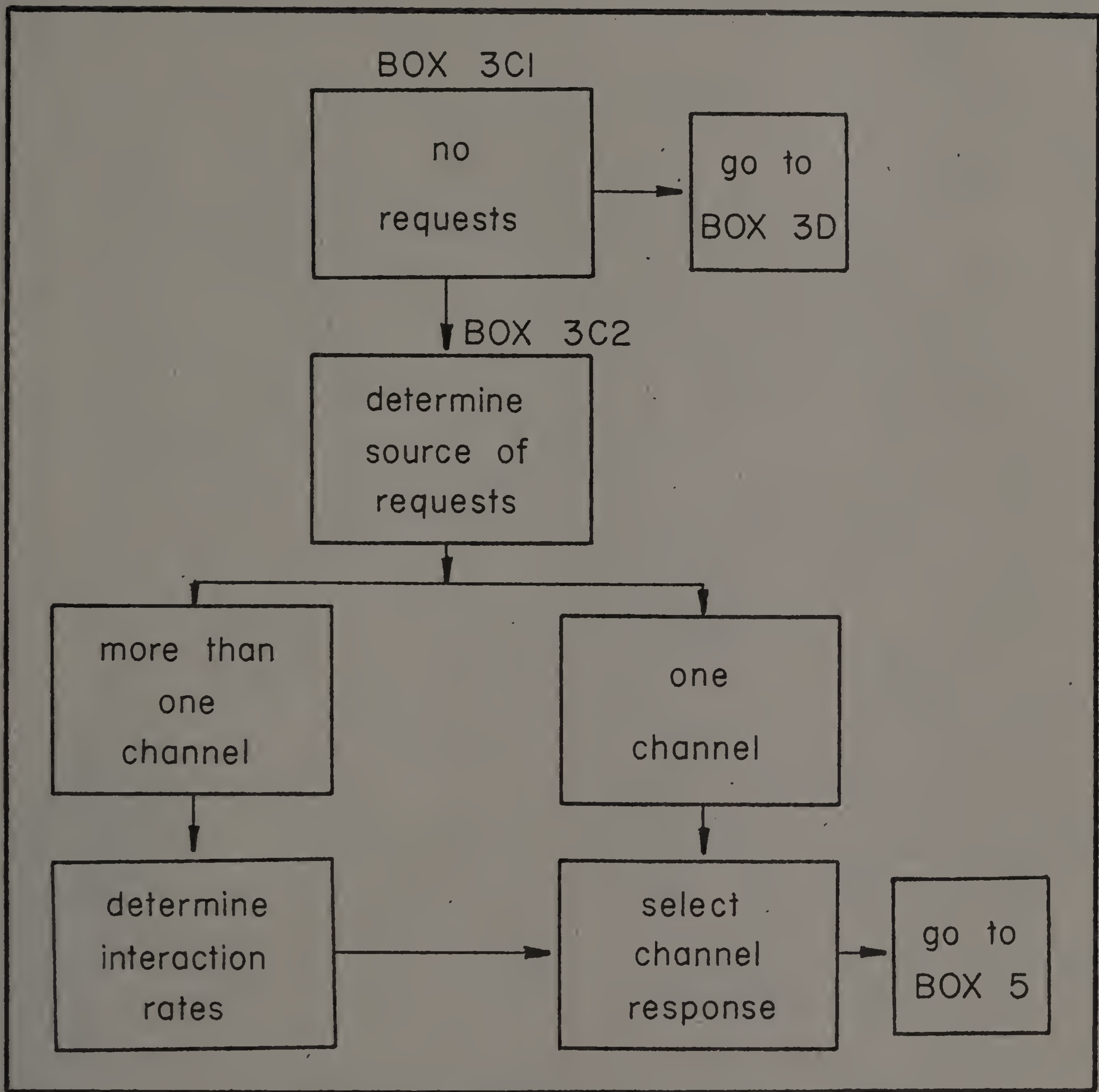
Let LST_{ij} = an index used to record data sent during the last round from MAN j to MAN i. where each element could be set = 1.0 in two ways. Either the element was a diagnal of the matrix or it was used when data had been sent from MAN i to MAN j.

The state of information since the last round for MAN j was then contrasted to his answer or information vector for round n to that of round n-1. When additional information had been collected after the request was made (last round), the appropriate response was made to the N_1 requestor (N_{1ij}) as in the three cases analogous to Box 3A2. When the information vector for MAN j had not changed, he returned to the start of Box 3B2 and began the search procedure anew. The state of information comparison can be expressed symbolically as:

$$N_{1ij} = k^* \text{ where } k^* \text{ is positive when } ANS^{t}_{k^*j} > ANS^{t-1}_{k^*j}$$

Box 3C Answer Requests. The search to evaluate outstanding requests for answers follows a process similar to Box 3B2, and is accomplished with a substitution of N_{2ij} for N_{1ij}. See Figure 3-5.

Box 3C1 Determine Source of Answer Requests. In the case where no answer requests have been made, $N_{2ij} = 0$ for all N_{2ij}, MAN j continues to Box 3D.



BOX 3C: ANSWER REQUESTS

FIGURE 3-5

Box 3C2 Determine Source of Answer Requests. The identical decisions for Box 3B2 must be made: the number and source of answer requests from all channels and their corresponding interaction rates. The selection procedure is the same and the mathematical representation is also identical except the substituting of N_{2ij} for N_{1ij}.

The resultant action, taken after a response to a request had been completed, was a decrement of the proper N_{nij} by 1.

Even a cursory observation of response behavior in actual CNE, would verify the suspicion that not all requests elicit responses. As reported earlier, Marshall pointed out that subjects did not respond to messages at times, even though they were sensible. There is evidence, though, in most of the CNE that response behavior does improve over time. At best, initial probabilities for response behavior were required at the initiation of the simulated runs. These probabilities would naturally increase or this behavior would improve with subsequent successful experience. A discussion of the determination of these input parameters is now presented.

<u>Responding to Information Requests</u>. In their problem solving, MEN had two types of distribution problems: those of information distribution and of response distribution. The first type of problem has been discussed above. The second type of problem arises from the necessity to coordinate responses to requests to achieve task completion. Depending on the nature of the contingencies between

responses to requests and outcomes, some, or all, of the MEN may be required to make a number of responses in one round. This requirement may be disjunctive in the sense that only some members need to make these responses. Bales and Strodtbeck (1951) indicated that subjects in task-solving groups do not increase these responses until the later stages of problem discussions. This finding begins to establish a rationale for setting the input parameters of response to requests relatively low at the inception of the simulation runs.

For the CNE paradigm, probabilistic relationships concerning the response to informational requests are not evident in both the CNE and group problem-solving literature. Although Leavitt (1951) and Cohen (1962) examined message content and sequence, neither systematically compared his results to this situation. They catagorized messages in a fashion similar to that of Bales' Interaction Process Analysis. Of particular interest were the number of: (a) data messages, (b) requests of any kind, (c) non-task related messages and (d) incorrect answers. They did not report the nature and amount of responses to any requests.

The frequency with which MEN responded to a request at the initiation of a run required input parameters which had not been empirically developed. A survey was then conducted by the author to determine a minimal range of probabilities for these actions. By evaluating trial outcomes relative to frequencies of responding to requests, MEN could be reinforced and increase these tendencies.

A detailed explanation of the task and physical constraints were presented to 86 randomly selected subjects. Two questions were then posed.

(1) How often would you send data in response to a data request?

(2) How often would you send data to a request for an answer if you had not determined the answer?

The inclusion of the second question was predicated upon the possible set of conditions in which requests for answers might be made. A further assumption regarding this situational conflict was included in the model. Even though a MAN would not have the answer, operating under the imposition of rational behavior, he might wish to respond. To this end, he would provide the most complete set of data he had. When a response was sent to this request for an answer, a MAN would send his information vector.

The respondents were asked to rate this behavioral tendency on a 100-point bipolar scale (ranging from 0 to 100). The results are displayed in Table 3-1.

TABLE 3-2

INITIAL RESPONSE RATES TO DATA AND ANSWER REQUESTS

Type of Request	Mean	Range	Standard Deviation
Data Request (question 1)	39.7%	20-78%	10.31
Answer Request (question 2)	10.2%	0-26%	3.92

The distribution of these observations around the mean statistic was observed to be leptokurtic. Leptokurtosis refers to a distribution with a pronounced peak. This clustering increased the confidence that the mean statistic was a relatively reliable estimate of the behavior advanced by the subjects. Confidence limits were then established for the population mean within 95% limits based on a t-distribution. These confidence limits were 39.7 ± 2.2 (85 D. F.) for responses to data requests and 10.2 ± 0.837 (85 D. F.) for responses to answer requests. This increased reliance that the mean statistic represented an appropriate initial probability. Therefore, 0.40 and 0.10 were applied as input parameters for responses to data requests and answer requests respectively.

Symbolically, response to requests are expressed as:

Let $P(RS_{nj})$ = The probability that MAN j would respond to request n, where n = 1, 2; n_1 = data request

n_2 = answer request

The artificiality of this survey (vis-a-vis observed behavior) again, imposes limits to the generalizability of the model. However, the costs to develop more precise probabilities would have been prohibitive; for this would have required establishing and running a number of CNE.

Box 3D Evaluate Waiting Period. It is reasonable that rather than sending messages, a MAN would do nothing, or wait. Indeed, this is evident in human subject behavior. Cohen's (1962) content analysis yielded not only several types of messages which he classified as stalling, or waiting, but also recorded periods of time when a subject was in a position to perform some constructive action, yet hesitated to do so. This phenomenon is also reported by Guetzkow and Simon (1955), Guetzkow and Dill (1957), and Cohen, Bennis, and Wolkon (1961), and Guetzkow (1965, p. 551).

The model permits waiting as a possible option in place of a message. However, because indeterminate waiting might prohibit a solution and is, indeed, not representative of subject behavior, the model limits a MAN to two successive rounds of waiting. Although there is no empirical evidence to support this artificial constraint, it appeared to be a reasonable facsimile of rational behavior. Nevertheless, the act of waiting in place of sending a message could be reinforced, and was done so with some frequency. The constraint was mathematically expressed as:

Let KWA_j = The number of acts of waiting in successive rounds.

where the range = 0, 1, 2

Box 4

Channel Selection

Initial probabilities for channel selection were included as input parameters. Raino (1965) suggested that in simulation models, all initial contact probabilities could be assumed to be equal. This is not an unreasonable initial situation for a group of strangers. Additionally, Bales (1951) noted that groups without an assigned leader tend to have equal distribution of participation among members. Without prior expectations regarding structure, pretrial information distribution, or knowledge of participants, no *a priori* statements can be made to support differential contact probabilities. This was introduced in the model by setting the initial probabilities equal. For MAN 4 in an All-Channel network this can be represented as:

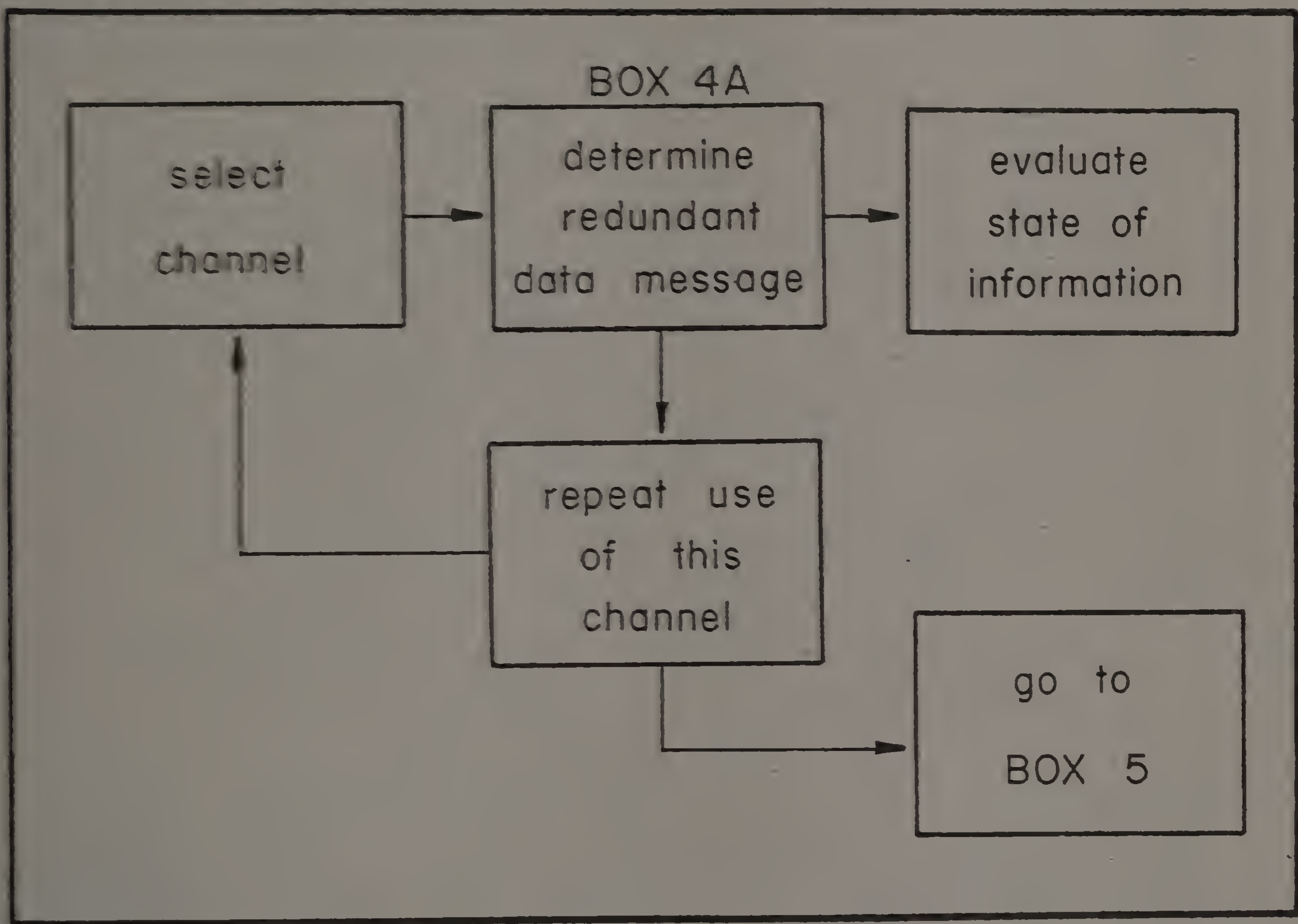
$$\sum_{i=1}^{3} P(C_{i4}) = 1. \quad \text{where } P(C_{14}) = P(C_{24}) = P(C_{34}).$$

Box 4A Determine Redundant Data Message. Recall in Box 3B2, that successive data messages through the same channel were restricted. When the searching process was repeated, (another message was selected) a MAN could, by virtue of his interaction rates $P(C_{ij})$, select the identical channel. The sequence of repetition was first choice of a message then of a channel. The procedure was selected to facilitate the model's construction. More decision branches occurred after a message selection than after a channel selection. Employing this sequence prevented repetitious looping in the computer program. Also, this programming technique contributes to lower running time on the computer.

Therefore, the redundancy restrictions were required in both respective selections. The outcomes and operation of this procedure were identical with the use of LST_{ij}. A flow diagram of Box 4 is presented in Figure 3-6.

There is abundant evidence that repetitious information is processed in problem solving groups. Macy, Christie, and Luce (1953) discovered that duplicate information transferred in their network experiments actually increased productivity in some cases. Baker, Ballantine, and True (1949) reported the use of repetitious data through one or two channels in management and union discussions. Further support is provided by Cyert and March (1963), Willis and Hale (1963), and Miller (1951). In CNE terms, although a data message was sent through a channel during the last round, the restriction imposed by LST_{ij} may be modified. A MAN might wish to repeat a data message. Observations in CNE demonstrate that there is a limit to redundancy, and it is subject-dependent. Cohen's (1962) content analysis descriptively reports this behavior.

To accommodate this behavior, the model permits repetition.



BOX 4: CHANNEL SELECTION
FIGURE 3-6

However, the more frequent its occurrence, the lower the probability becomes for its repetition within a trial. When the examination of LST_{ij} is positive, the $P(C_{ij})$ is modified by a correction factor V_r. Values for V were assumed to be linearly related to r such that $V_1 = 0.10$, $V_2 = 0.20$, $V_3 = 0.30$ and $V = 0.40$. This can be expressed mathematically as follows:

$$\text{when } LST_{ij} > 0, \ P^{t}(C_{ij}) = P^{t-1}(C_{ij}) - P^{t-1}(C_{ij})V_r$$

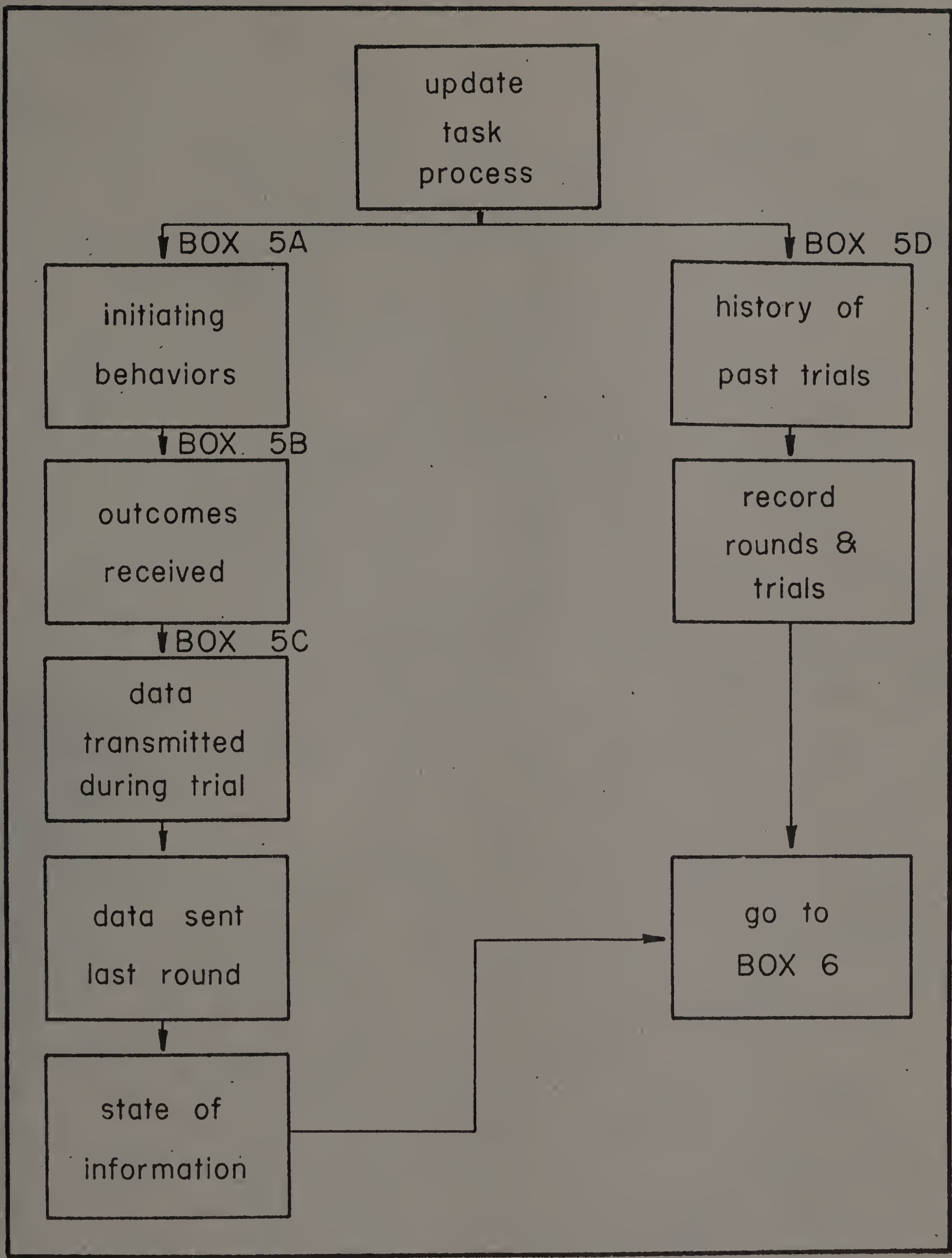
<u>Box 5</u>

<u>Memory</u>

To alter behavior, a memory was incorporated such that comparisons could be made relative to past experience. Both the MEN and the program recorded transactions which are delineated in Figure 3-7.

As a result of the two primary behaviors elicited in the model, each MAN was cognizant of two outcomes: his actions and those enacted upon him. Box 5A describes the first of these outcomes.

Box 5A Initiating Behaviors. A MAN sent messages through various channels during the course of a trial. As in Cohen's experiments where subjects began to record what they had done on a scratch sheet, the model permits each MAN to record his message and corresponding channel through which it was sent in a matrix.



BOX 5: MEMORY

FIGURE 3-7

This memory can be symbolically expressed as follows:

Let SN_{mji} = A counter whose value indicates message m sent sent to MAN i from MAN j, where m, i and j can take on values = 1, 2, 3, 4.

One more row was added to this matrix to accumulate the totals for all messages sent by each MAN to the other members through the open channels. This is expressed as $\sum_{m=1}^{4} SN_{mji} = SN_{5ji}$. The values in this row were used to determine which of these behaviors occurred most often for each MAN and would be learned.

Box 5B Outcomes Received. To determine which channels had contributed to greater task efficiency, a MAN recorded the number of messages sent to him from each channel. No waiting messages were counted, because the structure of the paradigm prevented recognition of its source. Symbolically these outcomes were expressed as:

Let RC_{mji} = A counter whose value indicates message m received by MAN j from MAN i, where m = 1, 2, 3; i = 1, 2, 3, 4; and j = 1, 2, 3, 4.

One more row was added to this matrix to accumulate the totals for all messages received by each MAN from the other members through the open channels, such that $\sum_{m=1}^{3} RC_{mji} = RC_{4ji}$. The values in this row indicated from which channel the most frequent messages were received for each MAN and are used to change the probabilities for channel selection.

Box 5C Data Transmittal During Trial. To record the frequency with which a data message was sent through the same channel during a trial (r), another set of vectors was utilized. Recall that this was necessary to apply the correction factor, V_r. This operation is mathematically expressed as:

Let DAT_{ij} = An index to record the number of data messages sent by MAN j to MAN i during a trial, where
$j = 1, 2, 3, 4$
$i = 1, 2, 3, 4$

The appropriate position in this matrix was incremented for every transfer of data, such that $r = DAT_{ij}$.

Box 5D History of Past Trials. The program registered cumulative experience in the trials for the readers' reference by accumulating the results of the outcome matrices SN_{mji} and RC_{mji} as $CUMSN_{mji}$ and $CUMRC_{mji}$ respectively.

Box 7

Learning and Altering Behaviors

When an individual performs in a non-group situation, increments or decrements in his proficiency occur as a result of the reinforcement he receives. Glaser and Klaus (1966) demonstrated that in their experiments it was possible to derive the same generalization about group performance from an analysis of the changes in individual member performance which occurred as a function of the reinforcement contingencies experienced by each member. In regard to group problem solving, Bales and Stodtbeck (1951), Borgatta and Bales (1955) observed that newly assembled groups are able to make only abortive attempts at task performance so long as the role structure remains undefined. Once the group has developed this structure, members are able to proceed with the task. This process of organization is what McWhinney (1964, p. 8) claims is largely indistinguishable from what others call group learning. In their work on CNE, Guetzkow and Dill (1957) supported a learning, or reinforcement, theory of role differentiation. Stogdill (1959, p. 168) summarized these findings in CNE by stating:

> Since the differentiation of role structures is facilitated by reinforcement, the development of organization may be regarded as a learning process.

A concise statement of this learning process was proposed by Egerman (1966). He surmised that in CNE-type groups an individual receives feedback through the channels of communication open to him. Clearly then, learning in some form must be included in a MAN's repertoire of behavior.

Egerman's findings suggested a stimulus-response relationship (S-R). The model incorporated the S-R approach by loosely basing the learning procedure on Thorndike's "law of effect." It is simply stated as the habit formation of stimulus-response connections depending not simply on the fact that the stimulus and response occur together, but on the effects followed by that response.

Psychologists have proposed several terms to suggest that a specific S-R relationship is being or has been learned. The most common terms have been "habit formation" and "memory." Habit refers to a functional relationship between the stimulus and the response. Formation refers to the establishment of these events as they occur over time. The term "habit strength" indicates how firmly a particular S-R relationship has been established. It is assumed to reflect the summation of effects for the amount of reinforcement and the number of reinforced repetitions. Hull (Osgood, 1953) postulates that the increment in habit strength becomes increasingly smaller as the training (number of reinforcements) progresses. Each additional reinforcement produces less strengthening of the habit formation than the one preceding it. In mathematical terminology this is described as a negatively accelerated function. These functions can be found readily in biological growth and decay phenomena.

In this study, the incorporation of learning took the form of a linear model developed by Bush and Mosteller (1955). They postulate that one subset of the sampled stimuli becomes conditioned to the response that occurred, and another subset becomes deconditioned to that response. Their formal model for reward training and rote learning permits reinforcement for one class of responses and no reinforcement for making all other responses. The assumption is made that the individual process in CNE more closely resembles reward training than any other. Symbolically, their proposition can be expressed as follows:

$$P^{t+1} = \alpha + (1-\alpha)\, P^{t}$$ where t = the trial number

$1-\alpha$ = base rate of change

Recently Allen and Estes (Tapp, 1969) have cast doubt on the effect on learning where subjects are unaware of the relationship between response and rewarding outcomes. Their work, however, presents no complications for the model, as the MEN are certainly aware of their actions and feedback channels once a solution is reached.

The previous studies indicated the relevance of feedback and reinforcement in altering individual behavior within group structure. The amount of change produced by feedback or reinforcement varies from study to study. A value for the rate of change in learning had to be obtained from the connectionist theory literature.

A study by Greenspoon (1955) indicated that under continuous reinforcement, the change in an individual's verbal output per trial period was approximately three per cent. The learning in this model generally occurred under a continuous reinforcement schedule. For tasks involving similar structures to CNE, Egerman (1966) found the order of most favorable schedules to be first, continuous, then aperiodic, only when correct answers were attained. However, since the paradigm permits only written communications, it seemed reasonable that this rate should be decreased when voice inflections and non-visible cues were absent. Thus the change rate would be less than three per cent per trial. Under this restriction, the value of $1-\alpha$ was set at two per cent. It should be noted that the rate of change, or learning, in the model should affect the dependent variable (solution rate) only by altering the slope of the curve over time, which may change the time to reach a steady state.

The behaviors altered as a result of trial experience are presented in Figure 3-8.

Specifically the crude learning model in this study operated in the following manner. When time taken to solution (number of rounds) improved over last trial, such that $CT < PT$, anthropomorphically, a MAN would think he had done something better than last time. The tendency to repeat these actions, according to the "law of effect" would then be incremented. In McWhinney's analysis of information-distribution processes in CNE, he indicated that

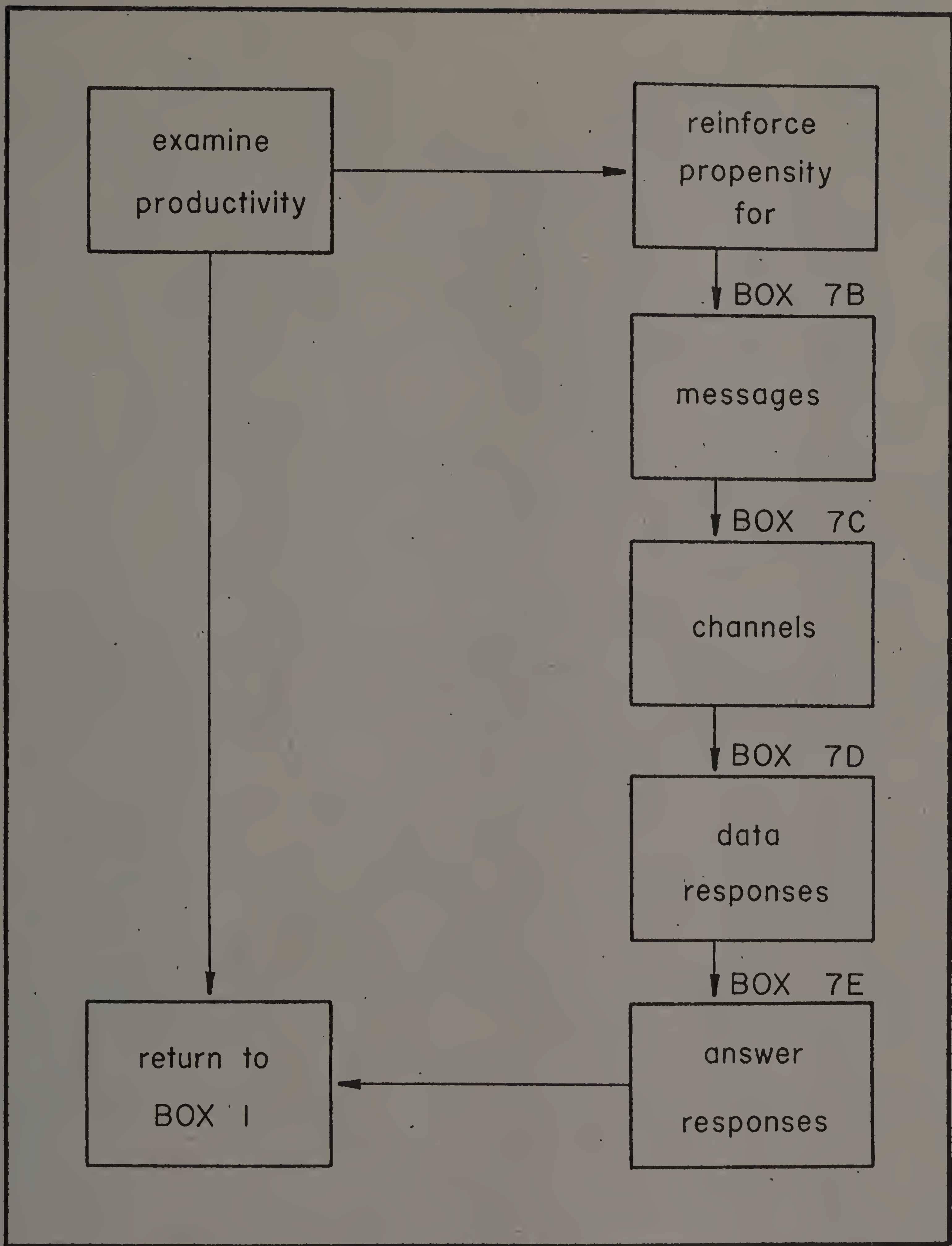
> . . . the character of cybernetic feedback mechanisms leads to repetitions of prior behavioral choices when "hits" and "good outcomes" occur.

The three actions whose probability could be increased are:

(1) $P(A_{ij})$, The probability of MAN j sending message i.

(2) $P(C_{ij})$, The probability of MAN j selecting channel i.

(3) $P(RS_{nj})$, The probability that MAN j would respond to request n.



BOX 7: LEARNING

FIGURE 3-8

Box 7B Messages. The two learning strategies which can be associated with CNE are (1) selective coding and (2) associations with patterns. Marshall employed the latter in his simulation model of CNE, but it was found to be network-dependent. His success was limited to only the network modeled and could not be productively applied to other structures. In this study, selective coding is used.

The strategy of selective coding involves the idea that when a person remembers something, he does not remember everything about it. Greeno (1968, p. 180) pointed out that any situation has many properties, and usually a person notices only a few things about the situation he is in. A person may have learned or increased the habit formation, an association between a stimulus and a response, but not have the whole stimulus represented in his memory. The memory of an association may include only a part, or an aspect, of the stimulus enough of its characteristics to permit a similar response, but not a complete representation. In network experiments by Raporport (Von Foerster and Zopf, 1961), selective coding was identified. Raporport further explained, that when one choice of information was reinforced by the individuals, the residual uncertainty was distributed equally among the remaining choices. To reflect these findings, a MAN identifies how frequently he sent each of the four messages during a trial. That which is sent most often is reinforced for that trial. When two or more messages are equally prevalent in highest frequency, the reinforced message is randomly selected. Consistent with Raporport's experience, the probabilistic increment for message i is equally distributed, and decremented from the probability of selecting the other three messages. This is represented mathematically as follows:

Let $P^t(A_{ij})$ = The probability that MAN j sends message i during trial t. If message k was most frequently sent during trial t, then

$$P^{t+1}(A_{kj}) = \alpha + (P^t(A_{kj})(1 - \alpha))$$

$$P^{t+1}(A_{ij}) = P^t(A_{ij}) - P^{t+1}(A_{kj})/3.$$

Box 7C Channels. Using selective coding again, a person in these networks can readily ascertain with whom he interacted. When trial n was shorter than trial n-1, a person may adjudge that channel from which he received the most messages as having contributed substantially to the improvement. Homans (1950) initially established the relationship that the greater the interaction between participants, the greater the liking or interpersonal attractiveness. Further, Collins and Raven (1969) report that the causal relationship between interpersonal attraction and communication rates are among the best-established propositions in social psychology.

It is conceivable that the MAN who sent the most task-relevant information (data) should be most liked. However, Bales' experience in problem solving groups indicates that the higher the instrumental activities (contribution toward solution), the less the liking. Loosely interpreted, the MAN who sends the most data or answers is not most likely to improve his interaction rates. Similarly, the model permits a MAN to select the highest number of messages received from a channel, and incremented this probabilistically. Random selection is employed when two or more channels are equally the more frequent. The remaining channels are decremented equally. This is symbolically expressed as follows:

Let $P^t(C_{ij})$ = The probability that MAN j receives a message from channel i during trial t. If channel k was most frequently used during trial t, then

$$P^{t+1}(C_{kj}) = \alpha + (P^t(C_{kj})\,(1 - \alpha))$$

$$P^{t+1}(C_{ij}) = P^t(C_{ij}) - P^{t+1}(C_{kj})\,/3.$$

Box 7D and Box 7E Responses. Recall that in the survey conducted to determine initial response rates, a substantial difference (0.30) existed between data and answer response rates. An assumption that differential increments to these rates, as a result of learning, would not be unreasonable. Using $\alpha = 0.02$ as a base, the ratio of 0.10/0.40 (the relative initial probabilities of responses) was adapted and applied to responses to answer requests. Mathematically, this is expressed as follows:

$$P^{t+1}(RS_{1ij}) = \alpha + (P^t(RS_{1ij})\,(1 - \alpha)) \quad \text{where } 1-\alpha = 0.02, \text{ and}$$

$$P^{t+1}(RS_{2ij}) = \alpha + (P^t(RS_{2ij})\,(1 - \alpha)) \quad \text{where } 1-\alpha = 0.005$$

Although no empirical evidence was established to support the answer response rate (0.005), the model did not prove to be substantively sensitive to this parameter. The rate 0.005 was set at the same ratio relative to 0.02 as the relative initial probabilities of responses (0.10/0.40).

Summary

This chapter presents a review of the relevant literature on the components in the simulation model of the CNE. The functional forms specifying the component relationships in the model are presented and discussed. All the assumptions incorporated in the model are included within the casual modular explanation of the process flows. Further, a laboratory experiment was conducted and the results were used in the models parameters.

The searching, comparing, remembering, and altering of behaviorsare tracedthrough the model flow without reference to the programming language. Having specified the components of the CNE, the model is used to test hypotheses concerning the effect of differing networks on task productivity. The results are presented in Chapter Five.

The next chapter presents a discussion of the methodology and statistical analysis employed in examining the simulation data.

CHAPTER IV

RESEARCH METHODOLOGY

Introduction

In the preceding two chapters, the simulation model's components and relationships were presented. The construction of the simulation model of a communication network, represents only one of the objectives of this study. The remaining objective is as follows:

> To investigate specific hypotheses regarding the effect of cumulative experience in task solving on the solution rates for selected communication networks.

First, the validation stage is done on the Circle network to verify the model's output and predictive ability. An experiment follows with an All-Channel network to investigate the hypotheses outlined in Chapter Two. To analyze the results, regression analysis was selected as an appropriate tool. The research methodology employed in this study is presented and will include the following topic areas.

(1) the output variable

(2) the hypotheses

(3) the experimental design considerations

(4) the statistical tools employed to analyze the experimental data

(5) the validation procedures and the analysis of the experimental data.

Output Variable

The objective of this portion of the study was to investigate the effect of cumulative task experience on the task solution rates. The dependent variable, task solution rate, was selected for several reasons. The improvement of communications within a small group may have an impact upon organizational stability, morale, organizational style, and interpersonal attraction, all previously examined within this paradigm.[1] Empirical relationships previously established between a productivity measure and the aforementioned variables could then be examined with additional information. It then appeared desirable to include a productivity measure as a focus for this study.

Second, prior investigations have demonstrated relationships between information distribution (Shaw, 1954), reinforcement stress (Lawson, 1964), opportunity to organize (Guetzkow and Dill, 1957), and productivity for short periods of time. These relationships may be time dependent. In his examination of group problem solving networks, Burgess stated (p. 324),

> These solutions exhibit a substantial transition period marked by an acceleration in the solution rate leading to a steady state. Differences in this orderly progression were still smaller when the groups were allowed to pass through the acquisition period to a steady state.

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[1] All of the previous studies cited in Chapter One have focused on one or more of these variables.

Although this output variable is an indication of some dimensions of organizational effectiveness, this was not the only reason for its selection. This variable was chosen to provide a link with the Burgess (1968) laboratory experiments. Recall that this study was used to partially validate the model. A simulation model must be validated if the experimental results generated from the model are to be meaningful. Van Horn (1968, p. 2) states that, "Validation refers to the building of an acceptable level of confidence in the model such that an inference about the simulated process is a valid inference for the actual process."

The three-stage validation procedure suggested by Naylor and Finger (1967) was employed in this study. Their final stage, the positive economics phase, requires a comparison of data generated by the model with that generated by a laboratory experiment. The Burgess (1968) study of communication networks is the only study conducted in the CNE where sufficient repetitions of a task were permitted, such that the aforementioned transition states in learning could be clearly identified.

It, therefore, was selected as the only benchmark against which the simulated results could be compared. The dependent variable in the Burgess study was productivity, or more specifically, task solution rates.

Operationally, this dependent variable was defined, in this study, as the number of time units (rounds) required to complete sequences of messages such that solutions were achieved by the network members per trial. This solution rate, time units per solution, is computed for each successive trial.

Independent Variable

The independent variable in this study--number of tasks or problems--can be equated to time; that is, the greater the number of problems, the longer the time needed to complete the experiment. This variable was chosen because empirical studies for particular CN have demonstrated its effect on the output variable.

In preceding chapters, the relevant studies concerning specific networks and productivity were presented. A review of the literature indicated the relationship between time spent on the task and productivity. In the following paragraphs a brief overview of the research which relates the independent to the dependent variable is presented.

With the exceptions of Burgess (1968) and Shaw and Rothschild (1956), communication experiments have been of short duration, constituting at most 60 trials. With the exception of Shaw and Rothschild, there has been no attempt to study the developmental behaviors of problem solving groups for longer periods of time. Shaw and Rothschild studied the performance (productivity) and satisfaction trends for four-person groups working for a short period each day for ten days, on fairly complex (arithmetic) problems. In one important sense, they helped answer questions raised about the temporary nature of the effects of prolonged experience on the behavior of subjects who have opportunities to rest between problem solving attempts. There is, however, another equally important kind of prolonged experience that groups may have. This is the kind in which participants work continuously for relatively long periods of time.

Cohen, Bennis and Wolkon (1961) indicated that time spent in task solutions was related directly to productivity or rates of problem solving. They indicated that this relationship was statistically significant between Circle and Wheel networks. Further, this rate was associated with interpersonal and task satisfaction. They also indicated that learning (improvement of solution rate) continued to take place in both communication networks for a considerably longer period than had been expected on the basis of studies of shorter duration. This improvement was represented by progressively more efficient operations through time.

Hypotheses

It was indicated in Chapter One that an objective of this study was to investigate several specific hypotheses on the effect of learning and reinforcement during cumulative task experience upon solution rates. The simulation model was constructed to provide a research vehicle to answer the following questions:

(1) What is the effect of prolonged practice or learning on the network's productivity rates?

(2) Is the rate of productivity affected by different networks?

To determine the effect of prolonged learning, two networks were evaluated, the Circle and All-Channel network. The Circle network is considered a two-step hierarchy, in that for a communication to reach any other level in the structure, it must pass through a two-stage procedure. The All-Channel network is a one-step hierarchy similar to a Wheel network. For a communication to reach any other level, it has to pass through only one stage. Operationally, the two structures are differentiated in the simulation model by:

(1) resetting the initial parameters for possible channels ($P(C_{ij})$) to constrict, or open, available paths.

(2) permitting learning to occur over a wider range of channels.

For both Circle and All-Channel networks the minimum number of messages required for a solution is six. Also, the minimum number of rounds to reach the answer is three for both networks. It was expected that both structures would reach, or approximate, optimal efficiency given a sufficient period of time. However, as mentioned earlier, the focus of empirical investigation in earlier studies was concerned with how soon each network reached this optimal level of efficiency.

Based upon the experimental evidence presented earlier in this chapter, three specific hypotheses can be formulated:

(1) In the long run, productivity measured by time units to solution for both Circle and All-Channel networks is equal.

(2) Solution rates measured by solutions per trial are equal for both Circle and All-Channel networks.

(3) The fewer the levels in the hierarchical structure, the sooner an optimal rate of productivity is reached. All-Channel networks reach a steady state solution rate in fewer cumulative solutions than Circle networks.

The null hypotheses for this study can be stated as follows:

> Cumulative experience in both Circle and All-Channel networks has <u>no</u> effect on productivity or solution rates for the respective structures.

Experimental Design Considerations

The objective of the experimental phase of the study was to systematically vary the structural configurations. An experiment was designed to study the effects of Circle and All-Channel structures on task productivity rates as a result of prolonged experience in task success. Because each statistic derived from a simulation run is a random variable, the experiments for both networks required replications. In experimental design terminology, a replication of an experiment is an independent repetition, or rerun, under as nearly identical conditions with the original run as possible. The independent repetition implies that experimental units are independent samples drawn from the population being studied. Employing the "Monte Carlo Technique," the entire experiment (two runs) was repeated by substituting a new seed, or starting value, for the pseudo-random number generators incorporated in the simulation model. Including the replications for both networks, twelve experimental runs were conducted in this study.

The length of each experimental run was 800 trials. This was dictated by several considerations; the ultimate aim of the experiment, the requirements of validating the data, and the computer time available. The intent of the experimentation phase of the study was to test specific hypotheses about prolonged experience in CNE. Because the model had no provision for decreasing returns due to exhaustion by the participants, the length of the study had to be of sufficiently short duration so that this model restriction would be realistic. Human subjects have persevered for, at most, 1000 trials (Burgess, 1968, p. 327). Also, the benchmark against which the simulated data is compared (Burgess, 1968) was comprised of 800 trials.

Regression Analysis. To examine the nature of the relationship between the variables produced in a time series, regression analysis was selected. This method was chosen both to examine the output data and to draw conclusions about dependency relationships which may exist in the time paths. When an estimate of a productivity rate can be made from a measure of cumulative experience and the experience comes first chronologically, it can be used to predict productivity rates. This relationship may be employed to predict to other situations. Regression analysis is used to examine this relationship.

When regression analysis is used merely to summarize the properties of data, the assumptions are not critical to fit data to the regression equation. To draw inferences from the sampled data concerning the population, the assumptions become critical. The assumptions underlying regression analysis are as follows:

(1) Both the independent and dependent variables are sampled from a bivariate, normally distributed population.

(2) The experimental error terms are normally distributed.

(3) The experimental error terms have homogeneous variances.

(4) The experimental error terms are independently distributed (error terms are not correlated).

(5) The sets of regressor values for the independent variable are fixed in repeated samples.

As a rule, the failure of an assumption affects the level of a statistical test. When the experimenter thinks he is testing at the 10 per cent significance level, he may actually be testing at the 14 per cent level. The net effect is to report significance where none may exist. The existence of an independently distributed error term is usually assured by randomly assigning the experimental subjects to the different blocks, or configurations, of the design. This approach cannot be used in simulation studies, as assignments are irrelevant. As with other simulation studies, this one will employ the "Monte Carlo Technique." It can be shown that the sample variance, considering each replication as an observation, is reduced (Conway, Johnson, and Maxwell, 1959).

With the exception of spectral analysis, most simulation users have attempted to draw inferences from their data by: (1) computing the sample mean and variance of a run, or experimental condition, (2) subject these statistics to t-tests to determine if observed differences in means are statistically significant. Because simulation data is generally indicative of autocorrelated time series, estimates of statistical relationships may be substantially underestimated, and differences between alternatives may appear significant, when in fact they are not.

A conversion of the regression equation to account for autocorrelated error terms by using a Durban-Watson d statistic has been suggested (Johnson, 1963). However, this approach is in general, not useful, because autocorrelation coefficient estimates for a finite time series are themselves autocorrelated (Kendall and Stuart, 1966).

The independent variable cannot be assumed to have properties which would support normally distributed and random assumptions. The dependent variable, solution rate, is event-dependent, or a function of previous occurrences. Its distribution cannot be assumed to have random characteristics. Consequently, the assumptions of normality and common variance are not met for tests of significance. However, for simply fitting an equation to data, in a descriptive sense, meeting these assumptions is not necessary.

This is essentially a learning model. The measure of auto-correlation from period to period is a measure of this learning. To remove this autocorrelation from the data to perform tests of statistical significance would be defeating the purpose of the model. In treating each run as an independent observation, tests of significance can be made, using the six observations for each network. Because of the size of this sample, no strong statements can be made. Therefore, given the nature of the data, the descriptive analysis used below was considered to be as good an indication of the relationships as possible. In this case, the coefficient of determination, r^2, can be employed as a measure of goodness of fit of the regression line. It specifies the amount of unexplained error not accounted for by the regression line.

In light of the aforementioned restrictions, the analysis of the output data was treated in similar fashion to Burgess' descriptive explanations (1968, pp. 341-344). A discussion of these methods is presented in the validation section.

Validation

To draw inferences from a simulation model to the real world, the model must demonstrate its ability to be relatively accurate. This is the purpose of model validation. Validation has been referred to as "the process of building an acceptable level of confidence that an inference about a simulated process is a correct, or valid inference about an actual process" (Van Horn, 1968). Although validation is an important facet of modeling, it is even more urgent in a socio-psychological simulation. Because such simulations possess low face validity, validation procedures become an integral part in the simulation strategy.

Naylor and Finger's (1967) multi-stage validation approach was adopted in this study. Their approach requires integrating the methodologies of rationalism, empiricism, and positive economics. They indicate that while each methodology is necessary, it is by itself insufficient for validating a computer simulation model. Rationalism holds that a model is a system of logical deductions from a series of synthetic premises. Thus, the first stage called for the formulation of a set of postulates, or hypotheses, describing the behavior of the networks. These postulated were formed from the already acquired 'general knowledge' of CNE or from similar systems which have been successfully simulated.

The empiricism stage does not permit any postulate that cannot be independently verified. Consistent with their suggestion, the functional forms specifying component relationships in the model were derived almost entirely from empirical data whenever possible. In Chapter Three, the related empirical evidence was cited for each relationship as it was sequenced through the model. Clearly, while the empiricism phase is a necessary step, it is not by itself sufficient to assure a reasonable level of verification. It is possible that each individual component may be well-established in its respective literature, but when these components are connected, the flow of behavior through the model may not result in an accurate representation of the real world. This problem is similar to attempts at combining theoretical constructs from different disciplines into a workable and verifiable theory. There have been few notable successes in these attempts, especially in the socio-psychological area (Miller, 1971).

Therefore, the final stage in this validation procedure should be a test of the model's ability to conform to or fit, observed behavior in the real world. Failure to pass this test would cause at least, serious doubts on the model itself and at most, would destroy previously established confidence. However, this test is essentially a null test. If simulated data do not agree with the observed behavior, the model would be extremely suspect.

Conversely, no strong statement can be made for the validity of the model when this test is passed.

Two approaches were taken in this final stage of the model's validation. The first was to check to the model's reliability, or the ability to produce, within probabilistic bounds, similar time paths for the output variable regardless of the sequence of pseudo-random numbers selected to produce movement in the model. A comparison of the correlation coefficient for the original series was made with every replicated run; however, these were visual and not statistical comparisons. If the case occurred whereby the model failed to pass a test of reliability, that is, the correlation coefficients for each replication were sizably different, it would indicate that the time series was highly dependent on the specific sequence generated from each pseudo-random number. Such a model would be again highly suspect.

The second approach to validation was a goodness of fit test, comparing the simulated results with that of a laboratory experiment. The Burgess (1968) CNE served as a benchmark. It should be noted that historical verification tests only whether the model as a whole can reproduce real world data. This procedure will not provide any assurances that functional specifications in the model are valid. Friedman (1963) claims that the validity of a model depends on its predictive ability rather than the validity of model assumptions. However, Clarkson (1962, p. 34) referring to his experiences with simulating investment portfolio selection procedures, commented that after a goodness of fit test, the problem of further verification is not so simple, because there is no clear way of testing either the functional form of the equations or estimates of parameters. This statement provides an additional reason for a multi-stage validation approach in simulation experimentation. Because a goodness of fit test cannot be used to validate the functional relationships in the model, the additional empiricism phase is necessary. Next, a detailed account of the validation procedures is presented.

Background on Burgess Study

In Chapter One, the Burgess CNE study (1968) was discussed. This long-term study investigated the identical independent and dependent variable employed in this study. The CNE simple problem was run in four man groups for 800 trials. For both Wheel and Circle networks, the relationship of time needed for solution per trial over these 800 problems was described by the function $Y = AX^B$. Descriptively, Burgess ascertained this fit by fitting his data to the following functions:

(1) $Y = A + BX$ (linear)

(2) $Y = A + B \log X$ (logarithmic)

(3) $\log Y = A + BX$ (exponential)

(4) $Y = AX^B$ (power)

where Y represents the number of messages required for solution and X denotes the trial number.

To determine the precision of these fits, he stated that the correlation coefficient (r) for each sample was highest for the power function. In every case, the power function best described the data with an $r^2 = 0.99$. No r^2's were reported for the other equations.

Further, Burgess found that the minimum number of messages for solution (a steady state) was reached for Wheel networks at approximately over 200 trials or problems. The Circle networks required over 300 trials to reach a steady state level. To validate more comprehensively the simulation model, not only must the simulated data conform to the power function, but the break points, or steady state achievement levels, also must conform.

The observational technique Burgess applied to his data to obtain the break points, or steady levels, is somewhat suspect. He developed a scattergram on logarithmic graph paper. Observing that an apparent discontinuity occurred in the data points after some number of trials, he inferred that in latter trials where a regression line could be drawn through these points, the slope of that regression line would be very close to zero. By inspection, he observed that there was a kink in the scattergram and proceded to draw two regression lines through the points on the logarithmic scales which reflected this break point. The underlying assumption of this method suggests that an inflection point, or second derivative, of the power function would indicate where this break occurred. However, for modified forms of an exponential function this inflection point cannot be analytically determined. A proper method would be to specify a rate of improvement, or slope, in the regression line after which the experimenter could operationally define that a steady state had been achieved. A range of trials in which this steady state was achieved in the simulated data for both validation and experimentation was identified by operationally establishing a rate of improvement. Both the choice and defense of this rate selected are presented in the results of Validation Three in Chapter Five.

Validation One: A Comparison of Original and Replicated Runs

The severe restrictions placed on inference tests by not meeting the assumptions underlying regression analysis, predicated a descriptive analysis for consistency between runs. For the original run and the five replications, the coefficients A and B will be inspected for their respective equality. Further, the coefficient of determination, r^2, will be examined. This coefficient indicates the amount of variation in Y which can be explained by a given relationship of Y on X. If most of the deviations from the regression line can be explained by the relationship Y on X, then,

r^2 should be close to $\pm$ 1.0. Following Burgess's (1968) evaluations, these examinations are conducted in a descriptive manner.

Validation Two: Comparison with the Burgess CNE Benchmark

Earlier in this chapter the results and methods employed in the Burgess (1968) study were presented. Overall group performance, as well as changes in performance leading to a steady state within restricted communication networks, were found to be very orderly phenomena. In each case his data were described precisely by a simple power function of the form $Y = AX^B$. For the four man groups working through 800 trials, the solution rate per trial was fit to the above function. The conclusion drawn from this study was that the behavior of problem solving groups followed the same general power law exhibited by such diverse phenomena as simple sensory responses and individual learning. Because the variables in this simulated study are identical to those in the benchmark study, the simulated data were fit to the power function. To simplify the fitting of the output data to the previously mentioned functions, a logarithmic transformation was performed on two of the four equations. The transformations were as follows:

(1) $Y = A + BX$ -- $\log Y = A + B (\log X)$

(2) $Y = AX^B$ -- $\log Y = \log A + B \log X$

The coefficient of determination (r^2) was observed as a measure of the precision of this fit.

Validation Three
Comparison with Steady State Levels of Achievement

To further verify the model's output, a comparison was made to match the steady state levels achieved by human subjects with those of the simulated data. The regression of time needed for solution on trial number was too gross to reveal that networks had reached a steady state. In order to show this, a rate was calculated. Specifically, the number of time units per solution was calculated and plotted against cumulative solutions. It was decided to use cumulative solutions rather than time in both the validation and the experiment, since the crucial variable affecting task performance would be experience in solving the tasks, rather than experience in just being in the network. This new equation described changes in productivity at each trial. The simulated data then should be described by a positively accelerated power function, but only up to a point. At this point there should be a discontinuity which marks the onset of a steady state. To identify this discontinuity, an initial rate of change must be calculated. The average rate of change for the first five trials was selected as that rate. When the slope of the regression line reaches the predetermined rate of change specified by the author, the break point, or steady state level, will have been achieved. This point will correspond to a value for cumulative solutions. The number of trials at which this occurs should conform to those specified by the benchmark study. These break points are calculated for all simulated runs.

Corresponding to these discontinuities, the coefficient of determination (r^2) should become smaller for each run, as these break points are approached. In a function which possesses asymptotic characteristics, the closer the asymptote is approached, the less the prediction can be made from the independent variable to the dependent variable. Specifically, the more cumulative solutions achieved, the less the information one has about any changes in solution rates. Thus, the gain in precision of the estimates which can be achieved after the operational steady state is reached should become very small.

Experimental Studies

It was previously mentioned that the length of the simulation run was 800 trials. The preceding section indicated that the complete laboratory study was used in the validation section of the study. After employing the Circle network for verification, the All-Channel network will be investigated for the aforementioned hypotheses. A descriptive analysis is used from the regression weights and correlation coefficients to examine the relationships postulated for productivity and networks. Specifically, both time for solution and solution rates are considered.

Summary

This chapter has presented a discussion of the output variables, the hypotheses to be tested, and the general approach to experimentation in executing this simulation study. A brief discussion of the regression model and its descriptive use is presented with the primary emphasis on the underlying assumptions for the use of this tool. After briefly discussing the techniques for analysis, the validation procedures for the study are presented.

In Chapter Five, the validation and experimental studies are presented and the results discussed.

CHAPTER V

RESULTS

Introduction

The development of the model and the foundation for the analysis of data were presented in the preceding three chapters. Consistent with the objectives of the study, an experiment was designed, and descriptive analyses were conducted, on the simulation model. The null hypothesis was as follows:

> Cumulative experience, or time trials, at the task has no effect on the solution rates and time required for solution for the communication networks.

In this chapter, the results of the experiment conducted on the model are presented. More specifically, the following topic areas are presented:

1. The Validation One results - Comparison for Consistency.
2. The Validation Two results - Historical Validation of the Simulated Results.
3. The Validation Three results - Comparison of Steady State Achievement.
4. The results of the Experiment.
5. A discussion of the findings.

Validation One: Results

The objective of the validation stage was to confirm the model's reliability. Reliability was previously defined as the ability of the model to produce consistent time paths for the output variable regardless of the sequence of Pseudo-random numbers which are used to drive the model.

When constructing an experiment with human subjects, the experimentation is designed so as to reduce the variability due to causes which are of no interest to the researcher, or are beyond his control. Experiments with simulation models do not have this problem. There are no sources of variability outside the experimenter's control. Certain aspects of reality must be introduced by a probability distribution. To simulate the real world, some variability must be introduced into the model. These events are caused to occur according to a probability distribution by use of pseudo-random numbers. This procedure can still yield a problem of excessive variability (in a sense, similar to the real world experiments). Two particular questions are of interest. (1) Will the introduction of a series of pseudo-random numbers produce too much variability in the model's output? (2) How similar are the original output variable time paths to the replicated time paths? If there is too much variability and the time paths are not similar, it would suggest that the output of the simulation is highly dependent on a particular sequence generated by the pseudo-random number. If the model's output is dependent upon a particular sequence, the model itself could be severely criticized. Excessive variability is operationally defined here by a 2% variance between all r^2's for both original and replicated runs.

To answer the two questions above, the output for both the Circle and All-Channel networks was compared. A descriptive analysis of the intercept (A) and beta (B) weights for the regression is included along with the coefficient of determination (r^2). The results of all runs is summarized in Tables 5-1 and 5-2.

Alpha describes the point of intercept on the dependent variable axis. It was expected that these points should not exhibit excessive between-run variability. The alpha values for Circle networks, listed in Table 5-1, show the range to be from -3.977 to -3.398. For All-Channel networks, the values in Table 5-2 indicate a range from -4.020 to -3.429. Further examination of these tables indicates that the standard error for both alpha and beta (deviations of the estimates from the true value) is relatively the same. This demonstrated additional evidence that between-run variability for both networks was quite small. As mentioned in Chapter Four, statistical inference tests were not conducted on any of the weights from the regression. However, for a regression line over 800 data points, both the original and replicated runs for both networks were adjudged to be reasonably consistent.

The beta weights for these regressions yield similar results. Table 5-1 lists for Circle networks a range of 1.276 to 1.222. The range for the All-Channel networks, shown in Table 5-2 is from

TABLE 5-1

REGRESSION ANALYSIS
FOR CIRCLE NETWORKS

Run Number	A	B	R^2	Standard Error of A	Standard Error of B
1	-3.668	1.239	0.9944	0.0248	0.0032
2	-3.977	1.276	.9956	.0227	.0029
3	-3.744	1.258	.9966	.0192	.0025
4	-3.729	1.259	.9962	.0202	.0026
5	-3.398	1.222	.9976	.0152	.0020
6	-3.862	1.273	.9954	.0229	.0030

TABLE 5-2

REGRESSION ANALYSIS
FOR ALL-CHANNEL NETWORKS

Run Number	A	B	R^2	Standard Error of A	Standard Error of B
1	-4.020	1.294	0.9980	0.0153	0.0020
2	-3.250	1.193	.9918	.0287	.0038
3	-3.429	1.200	.9940	.0249	.0032
4	-3.745	1.251	.9940	.0259	.0034
5	-3.860	1.266	.9984	.0135	.0017
6	-3.643	1.243	.9934	.0268	.0035

1.294 to 1.193. Although the estimates for beta are gross indications of the shape of the function, for a sample of 800 observations it appeared reasonable to assume that the range of these values was approximately equal and relatively stable for both networks.

The coefficient of determination is used as an estimate of how well the data points fit the regression equation. It indicates the degree of variation from the regression line which can be explained by the dependent-independent relationship. Variability is introduced through a pseudo-random number generator. If the amount of unexplained between-run variation is large, it could be said that this difference in variability for the output is excessive due to the sequence of random numbers. For both networks, Tables 5-1 and 5-2 indicate an r^2 of 0.99+ for all twelve runs. This is a further demonstration of the model's ability to produce consistent time paths regardless of the selection of a pseudo-random number used to drive the model.

Validation Two: Results

The objective of this phase of the validation portion of the study was to compare the data (coefficients of determination)[1] with the results of the Burgess CNE (1968). One conclusion drawn from that laboratory study was that productivity of problem solving groups

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[1] Only this statistic is reported without any indication of either the alpha or beta weights.

(Wheel and Circle networks) in CNE can be described by a power function of the form $Y = AX^B$.

Visual comparisons were made between the simulated and real world data for Circle networks. The coefficient of determination was computed for each Circle run over the 800 trials, or cumulative solutions. The results are presented in Table 5-1.

The findings in this study particularly agree with Burgess' conclusions. In each instance, the power function best described the data. The r^2's, for the six runs reported, were 0.99+. This is every bit as good a fit as those obtained by Burgess. His r^2's for ten experiments were 0.99 using the funcion $Y = AX^B$. Evidently, group problem solving behavior produced by the model is as lawful as psychophysical phenomena; and it appears to follow the same general power law. For linear fits, as a comparison, the r^2's were .54.

Further, as Burgess concluded, with individual learning, the simulated groups similarly exhibited an initial transition period during which their response rates steadily increased. Additionally, organizational patterns developed as reported by Marshall (1966). As observed in all network structures, a pattern of relaying messages had either been achieved, or was in process, when CNE of short duration had ended. These patterns were reflected in the model by the probabilities of channel selection. In almost every case, each group (run) had developed an organizational structure which persisted throughout the 800 trials. Also, the structures were substantially different for each group.

Validation Three: Results

Another problem investigated in the Burgess study (1968) was whether there are differences between the Circle and Wheel networks in the transitional stages leading to a steady state. He examined the developmental behavior of these task groups to answer this question, as well as to provide a replication of results obtained in his first experiment. It was found that achievement of a steady state solution rate was reached by Wheels earlier than Circle networks. The concern here was that no difference in solution rates were observed between networks during the steady state periods. With contingencies of reinforcement in effect, no significant differences occurred with regard to solution rates. To determine the relative productivity for each network, the point at which the transition stage ended and the steady state level was reached was computed. Burgess reported that it took groups operating as Circle networks a little over 300 trials to reach this steady state.

To the extent that the simulated data for Circle networks conform to this break point, or onset of a steady state, confidence in the model's predictive abilities would be enhanced further. As previously mentioned in Chapter Four, the observational technique employed by Burgess was not deemed satisfactory. Rather than estimating a point of inflection for a change in the rate of productivity, a rate was selected (points of inflection cannot be determined by a second derivative in power curves). After groups have achieved this rate of change operationally, a steady state condition was in effect. The operational definition of a steady state attained in this study was set at 0.05 of 1% improvement of the solution rate relative to the starting conditions or initial rate. For the first five trials, an average was calculated, and was used as the initial productivity rate. Once the solution rate per trial reached 0.05 of 1% of the averaged first five trials, the steady state had been achieved.

The selection of the critical rate (0.05 of 1%) was predicated upon the need first to choose a break point and second, to be reasonably certain that it was small enough to assure that very little improvement occurred thereafter.

If the equation employed in the second validation described overall productivity, the equation for this validation step describes change in productivity. This equation is a first order differential relative to Y of the first equation which takes the form:

$dY/dX = A^{1/B}B(y)^{(B-1)/B}$; where dY/dX = solutions per time unit; Y = cumulative solutions; $A^{1/B}B$ and $(B-1)/B$ are empirically determined constants. The solution follows:

$$Y = AX^{B}$$

$$X = (Y/A)^{1/B}$$

$$dY/dX = AB(X)^{B-1}$$

$$= AB(Y/A)^{(B-1)/B}$$

$$= A^{1.} \; A^{-1+(1/B)}B \cdot Y^{(B-1)/B}$$

$$= A^{(1/B)}BY^{(B-1)/B}$$

A regression was obtained for the six runs of the Circle network using the above function. (This equation was also used in the experimental phase of the study for All-Channel networks.)

The beta weights for these regression lines indicate the slope, or rate of change in productivity. However, what is of concern is the slope, or rate of improvement, at selected cumulative solutions. An attempt was made to determine after how many trials, or how much experience, did the rate of productivity fall to an insignificant level.

A series of regressions was obtained from all six Circle runs by dropping earlier observations, then recording the slopes or beta weights for the remaining data points. Tables 5-3 through 5-8 present a summary of these regressions.

The critical rates for steady state achievement in Circle networks calculated for a 0.05 of 1% based on the average of the first five trials and are presented in Table 5-9. First, sets of regression were constructed by dropping from the data base a given number of

TABLE 5-3

REGRESSION ANALYSIS
FOR CIRCLE NETWORK ONE

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000145	0.000010	0.2725
250	.000126	.000011	.1941
300	.000103	.000013	.1170
350	.000093	.000015	.0795
400	.000092	.000018	.0601
500	.000087	.000029	.0296

TABLE 5-4

REGRESSION ANALYSIS
FOR CIRCLE NETWORK TWO

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000165	0.000010	0.3122
250	.000157	.000012	.2543
300	.000162	.000013	.2324
350	.000156	.000016	.1816
400	.000145	.000019	.1276

TABLE 5-5

REGRESSION ANALYSIS
FOR CIRCLE NETWORK THREE

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000132	0.000010	0.2067
250	.000131	.000012	.1907
300	.000122	.000013	.1429
350	.000123	.000016	.1158
400	.000115	.000020	.0785

TABLE 5-6

REGRESSION ANALYSIS
FOR CIRCLE NETWORK FOUR

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000105	0.000010	0.1637
250	.000102	.000011	.1335
300	.000097	.000013	.1016
350	.000084	.000015	.0647
400	.000094	.000018	.0631

TABLE 5-7

REGRESSION ANALYSIS
FOR CIRCLE NETWORK FIVE

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000139	0.000010	0.2344
250	.000130	.000012	.1827
300	.000124	.000014	.1468
350	.000130	.000016	.1302
400	.000122	.000019	.0953

TABLE 5-8

REGRESSION ANALYSIS
FOR CIRCLE NETWORK SIX

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000123	0.000010	0.2081
250	.000111	.000011	.1537
300	.000111	.000013	.1259
350	.000109	.000015	.1022
400	.000099	.000018	.0928

initial trials. Then, by comparing the critical rates of productivity for each Circle run in Table 5-9 with its respective set of regressions in Tables 5-3 through 5-8, the following observations can be made. For runs 1, 3, and 5, the slope of the regression lines are approximately equal to the critical rate at 300 cumulative solutions, or trials. For run 2 this equivalence occurs slightly before 250 cumulative solutions, and just after 200 trials for run 4. The last comparison for run 6 indicates that the break occurs at slightly over 300 trials.

TABLE 5-9

CRITICAL RATES FOR STEADY STATE ACHIEVEMENT IN CIRCLE NETWORKS

Run Number	Average Rounds First Five Trials	Critical Rate
1	18.0	0.000111
2	12.8	.000156
3	16.4	.000122
4	19.2	.000104
5	16.1	.000124
6	18.4	.000108

These beta weights could not be statistically tested for the reasons mentioned in Chapter Four. However, these observations tended to reassert that the model was reasonably accurate in determining equivalent breaking points. Although the discontinuities described by Burgess did not occur after the identical number of cumulative solutions in every case, the majority of the simulated runs did break at about 300. The range of break points for the other runs leads the author to assume a mean value for all runs at slightly under 300 cumulative solutions.

Another important point of this validation section was to establish a range of cumulative solutions in which discontinuities in productivity rates did occur; for while there may be no ultimate differences in solution rates for different networks, it has been suggested (Burgess, 1968; Cohen et al. 1961) that there are some initial differences between networks. Identifying a range of cumulative solutions for Circle networks at which discontinuities occur in improvement, provides a measure, or benchmark, against which other networks can be compared. A contrast between All-Channel and Circle networks, made in the experimental phase of this study is to identify the different transition stages based on the power curve.

An examination of the coefficients of determination for the Circle runs (see Tables 5-3 through 5-8) suggests there is more variability in productivity the greater the experience. However, as more earlier cumulative solutions are dropped, the results produced by the regression line are, in a sense, caused by losing part of the curve in the power function. In this case, another interpretation is required. Using the linear case, $Y = A + BX$, to explain what occurred, as more, earlier cumulative solutions were dropped, the constraints on the regression line began to approach the condition where $A = \overline{Y}$ and $B = 0$. Therefore, all data points remain as unexplained deviations. Hence, a poor fit, or a large amount of variation, not explained by the regression remains. The range of these equidistant data points is also important. In the output data, the range of points is from three to four. Three rounds is the optimal number of Circle groups. It is expected then, that the smaller the r^2's, or as r^2 approaches zero, the better the goodness of fit. This means that the greater the experience in task solutions, the greater the expectation that the coefficients of determination will become smaller. The regression lines for all Circle runs indicate this case to be in effect.

Overall, the validation studies increase the face validity of the simulation model. This is an important step in sociopsychological simulations as these models possess low face validity. Because these models are constructed without the benefit of a general analytical model (such as queueing models which possess high face validity), a validation phase is an absolute requirement.

A caveat should be tendered. Evidence that the model's output agrees with a given benchmark study does not mean that under different experimental conditions the model would be a valid representation of the real world. Nevertheless, to the extent that the model successfully passes a series of validation requirements, the investigator is more confident in the model's predictive abilities. In the next section, the results of the experimentation phase of the study are presented.

Experiment: Results

Recall from the previous chapter that the experimental phase of this study is based upon measures of productivity for All-Channel networks. Two sets of regression analyses were conducted on the All-Channel data. Comparisons were then made to the data for Circle networks. First, regression was applied to 800 trials for the All-Channel network by regressing time units per solution on cumulative solutions. Second, regression was conducted on the rates of solution on cumulative solutions at selected levels of task experience. The findings on the output variable from the first series of regressions are presented, followed by the analysis on the solution rates.

Findings on Time to Solution. In Table 5-2 the alpha and beta weights are presented with the coefficients of determination for all six runs over 800 trials for All-Channel networks. The values for

r^2 are to read as a percentage. The functional equations used to fit the data are similar to those used by Burgess (1968), and previously employed in the validation phase of this study. The significant findings may be summarized in the following manner.

1. The time to solution per trial for All-Channel networks can be best described by the function $Y = AX^B$.

2. As with Circle networks, the All-Channel groups reached an optimal level of performance for the structure.

3. Similar to individual learning, All-Channel groups exhibited an initial transition period during which their response rates steadily increased until a steady state was achieved.

Findings on productivity rates. This section presents the results of a series of regressions used to determine discontinuities in productivity rates. Employing the same method of dropping data points used in Validation Three, alpha and beta weights with the coefficients of determination for the six All-Channel runs are presented in Tables 5-10 through 5-15.

To adjudge the relative productivity and achievement of a steady state the critical rates for this network were computed. Similar to the method employed for Circle networks, an average for the first five trials was used as a base to determine the point at which change in solution rates fell to 0.05 of 1%. These results are presented in Table 5-16.

REGRESSION ANALYSIS FOR ALL-CHANNEL NETWORKS

TABLE 5-10

All-Channel 1

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000133	0.000011	0.2024
250	.000126	.000012	.1577
300	.000107	.000014	.1016
350	.000114	.000017	.0941
400	.000093	.000020	.0585

TABLE 5-11

All-Channel 2

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000154	0.000011	0.2424
250	.000136	.000013	.1734
300	.000128	.000015	.1321
350	.000115	.000017	.0880

TABLE 5-12

All-Channel 3

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000152	0.000011	0.2428
250	.000141	.000013	.1857
300	.000145	.000015	.1616
350	.000144	.000017	.1337

TABLE 5-13

All-Channel 4

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000157	0.000010	0.2917
250	.000147	.000012	.2303
300	.000138	.000014	.1726
350	.000122	.000016	.1179

TABLE 5-14

All-Channel 5

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000140	0.00011	0.2247
250	.000137	.000012	.1848
300	.000129	.000014	.1419
350	.000113	.000017	.0926

TABLE 5-15

All-Channel 6

Number of Trials Dropped	B	Standard Error of B	R^2
200	0.000121	0.000011	0.1799
250	.000112	.000012	.1362
300	.000097	.000014	.0877
350	.000095	.000016	.0699

TABLE 5-16

CRITICAL RATES FOR STEADY STATE ACHIEVEMENT FOR ALL-CHANNEL NETWORKS

Run Number	Average Rounds First Five Trials	Critical Rate
1	16.0	0.000125
2	14.1	.000142
3	12.6	.000159
4	12.8	.000156
5	14.2	.000141
6	13.1	.000153

A comparison of Table 5-16 with the Tables for each respective All-Channel run indicates the discontinuity in transition stages for these groups to occur between 200 and 250 trials, probably somewhat closer to 200 cumulative solutions. For runs 3 and 6 the onset of a steady state occurred prior to 200 trials. At approximately 200 cumulative solutions, the critical rate was achieved in runs 4 and 5. Run 1 stabilized at 250 trials and run 2 between 200 and 250 trials. These findings may be summarized as follows:

1. All-Channel networks achieve a steady state solution rate at slightly over 200 cumulative solutions.

2. The onset of a steady state for solution rates in All-Channel networks occurs before Circle networks.

Discussion of Findings

The findings in this study tend to support the three hypotheses which were formally stated in the previous chapter. The hypotheses are as follows:

1. In the long run, productivity measured by time units to solution for both Circle and All-Channel networks are similar.

2. Solution rates measured by solutions per trial are similar for both Circle and All-Channel networks, in the long run.

3. The fewer the levels of hierarchical structure, the sooner an optimal rate of productivity is reached. All-Channel networks reach a steady state solution rate in fewer cumulative solutions than Circle networks.

The first hypothesis was clearly supported by the findings in this study. Overall, the level of productivity in problem solving for both networks approached and maintained the minimum time (in rounds) required to complete successive tasks. There were no differences in these times, as both networks used three or four message opportunities after long run experience.

The second hypothesis was also supported by the findings. The solution rates achieved in the long run for both Circle and All-Channel networks were the same. Between 0.33 and 0.25 solutions per trial were recorded for each network in all replicated runs after substantial experience.

The third hypothesis was clearly supported by the findings of this study. Circle networks, which are two step hierarchies, require a minimum of two relays to reach any other member of the network. These networks took longer to reach a steady state solution rate, approximately 300 trials. In contrast, All-Channel networks, which are one step hierarchies and require one relay of messages to reach any other group member, achieved a steady state solution rate earlier than Circle networks. They achieved this solution rate at slightly more than 200 cumulative problems. Groups in the All-Channel networks will solve problems with fewer communications, and reach minimum times for solution before the two step hierarchy.

In summary, group problem solving behavior exhibited a substantial transition period evidenced by an acceleration in the solution rate leading to a steady state. Contingencies of reinforcement permitted both networks to achieve and maintain these steady state periods. Additionally, the networks differed throughout the transition periods: the Circle performed initially at a lower rate than the All-Channel; it reached a steady state somewhat later than the All-Channel and it took the Circle substantially longer than the All-Channel to reach optimum organization. These observations are based on a rough comparison on the ranges of break points in transition states, or achievement of steady states, between the two networks.

A discussion of these findings relative to alternative explanations found in the group problem solving literature follows, and will include (1) the nature of the task, (2) learning and information exchange patterns, and (3) opportunities to organize.

Some discrepancies in performance between Circle and All-Channel networks were discussed from an evaluation of Table 2-1. For the simple task, three All-Channel networks were not as productive as Circles or Wheels. However, nine All-Channels were faster than the one-step hierarchies. Separating these findings by the task used in each study still does not explain these differences. Upon examining the results of this study, it can be seen that there was a gradual yet steady acceleration in solution rates. Eventually, all groups for each network reached a steady state. Consequently, one must question the generalizability of the findings from previous investigations, particularly since the maximum number of solutions before this was 60. If it took this long to reach a steady state with simple problems, the findings from studies incorporating complex problems should be especially questionable. One would expect the attainment of a steady state in those circumstances to be altered drastically. These results strongly suggest that to compare properly the effects of communication structures, a group should have enough experience as an operating group to achieve optimal performance.

Differences may have existed in CNE of short duration using the simple problem; however, these may not have been significant differences when compared to cumulative experiences of longer duration. The output data from the simulation did indicate that one Circle group was initially faster than some of the All-Channel groups; nevertheless, that one group did not achieve a steady state solution rate until 250 trials. Thus, some previous findings for the differences in initial rates of performance may have been transitory.

One final point should be made: Steady states and optimal organization may vary independently of one another. For example, a group may reach a steady state that fails to employ optimal organization, as was found to be the case with one group. Likewise, a group can attain an optimal organization before reaching a steady state, as was the case for a time with three groups.

The findings of this study argue for the design of socio-psychological experiments to permit the observation and analysis of the entire developmental histories of groups from their transition periods to their steady state periods. The findings also suggest that one important variable which must be included to explore properly the effects of various communication networks and possibly social structures in general is learning.

One conclusion which can be drawn from previously asserted differences in solution rates between communication structures, in which there were no physical limitations favoring one network over another, is they were a function of experimental artifacts. Had previous experimenters included reinforcement contingent upon behavior, and had they observed their experimental groups over sufficient time periods, the collection of a vast array of contradictory findings may have been avoided.

The simulation data suggest that a steady state, at least within the operational limits, may not be some biological limit, but rather an equilibrium--a dynamic equilibrium--based on a balance between energy output and reinforcement input. What psychologists have learned about schedules of reinforcement may be of major importance here (Ferster and Skinner, 1957). Laboratory investigations have repeatedly demonstrated that variable reinforcement schedules are superior to fixed schedules in sustaining performance. However, as Egerman (1966) stated, in group situations a continuous reinforcement schedule may be superior. The findings in this study would have been affected if variable schedules had been employed. Transition stages would have been longer and the maintenance of a steady state may have been disrupted. The results of both the validation and experimentation phases of this study support Egerman's contention.

In Chapter One, it was suggested that individual learning accounted for differences in performance between networks of dichotomous hierarchies. Burgess' study found that Wheel networks achieved optimal organization sooner than Circles. To account for this, it was suggested that productivity differences for Circle groups could be attributed to more complex sets of stimuli (having to compare messages and channels for two or more members rather than one). It would appear that for All-Channel networks the sets of stimuli would be even greater than those for Circles. This is not the case in both laboratory experiments and the simulated data. While it is true that in most social groups all members may communicate with all others, making the group similar to a totally connected network, it has been shown (Miller, 1971) that the actual working structure of totally connected groups in network studies often involves only certain channels, making it similar to one of the other more limited networks. Thus, it is conceivable that All-Channel networks have the option to develop a structure similar to Wheels. That is, members may develop such that one member becomes the solver and receives information from all other channels. It is conceivable for an All-Channel network to behave as if it were a Wheel. When and if this situation occurs, it would be expected that their performance would be identical to Wheels.

The real world data from Burgess' experiments indicated that Wheels achieved a steady state solution rate at approximately 200 trials. Contrasted to the simulation data for All-Channel networks, the onset of these states occurred at about the same time in cumulative experience (slightly over 200 trials). More conclusively, three of the All-Channel networks in this study organized such that their channels of communication approached and resembled those of a Wheel network.

Even in the earliest trials for both networks used in this study, performance was better than random. As the number of trials increased, the number of messages and time required in trials decreased, the amount varying from All-Channels, which improved fastest, to Circles which improved more slowly. The apparently local rational behavior of individual members, the reinforcement of successful behaviors, and the topological properties of the networks seemed to account for these differences. The curves of group improvement were often, but not always, smooth and slow. On no occasion did one or two successive minimum solution times alter performance from few perfect solutions to continual minimum times. The resultant information exchange patterns continually produced output which could be described by the biological growth function $Y = AX^B$.

From the evidence produced in this study, it appears that when learning-and the effects of reinforcement-are considered and included in an experimental situation, any network could achieve performance rates which would be similar. The predictive factors would be length of cumulative experience and the structural restrictions of the network.

In a series of papers, Guetzkow and his associates have taken off on a somewhat different tack from the original Bavelas-Leavitt studies (Guetzkow, 1960; Guetzkow and Dill, 1957; Guetzkow and Simon, 1955). Guetzkow and Simon argue (1955, pp. 233-234)

> . . . that a sharp distinction may be made between: (a) the effects of communication restrictions on performance of the operating task; and (b) effects of the restrictions upon a group's ability to organize itself for such a performance. That is, instead of regarding the group's problem as unitary, it appears essential to separate the operating or substantive task from the organization or procedural problem.

The major Guetzkow hypothesis, then, is that if groups are able to achieve a satisfactory interpersonal organization, there will be no differences in the amount of time required to solve the Leavitt task. His primary method used to investigate the hypothesis was to permit intertrial organizational types of communication. Refuting both Guetzkow's hypothesis and supportive findings, Schein (1958) employed a similar experimental paradigm and reported that efficiency preceded organization. The ensuing comparisons of this phenomenon concluded with Shaw's criticism (1964, pp. 134-135) that support for the Guetzkow hypothesis was correlational. Defining organization as an established pattern of channel use, the findings of this study tend to support Schein's observations that efficiency precedes organization. For all simulated runs, communication patterns between channels did not stabilize until efficiency had been established. Although it is possible that organization could stabilize before efficiency, minimum solution rates would not be achieved.

Reinforcement was a key variable in the model. Stable organization appeared after efficiency had been achieved.

CHAPTER VI

SUMMARY

Introduction

The purposes of this study were:

1. To determine the feasibility and desirability of the simulation methodology for the study of socio-psychological phenomena in group structure.

2. To investigate the rates of productivity for selected communication networks.

To accomplish these ends, first, a simulation model of individual behavior in communication networks was constructed. It was derived from and composed of existing propositions from learning theory, psychological theory, and the communication networks experiments and caused these to interact. The propositions of psychological theory deal with the behavior of individuals and the conditions of equilibrium in the group. The nature of the model and the networks' paradigm permitted equilibrium states to be a function of the summation of individual behaviors. In these limited social conditions, these propositions consider behavior as an exchange of information between persons. The differences in the rates of communication are explained in terms of interaction rates and interpersonal liking. The relevant theory and empirical findings that were used in the construction of the simulation model were presented in Chapter Three.

Next, the experimentation phase of the study was conducted. The two phase program included a validation and experimental study. The need to validate models has been discussed previously. Validation is a process which enables the researcher to develop confidence in the ability of the model to predict the behavior of the real world. In this study, the Naylor and Finger (1967) multi-stage validation procedure was employed. In the construction of the model, the empiricism stage of this procedure was evident. The functional forms specifying the model's component interrelationships were derived almost solely from empirical evidence. Data from laboratory studies were used to determine the proper functional specifications and the parameter values for these specified relationships. Further, in one instance, the parameter values necessary for the model's operation were unavailable in the group problem solving literature. An experiment was conducted by the author to secure the relevant data required to establish these necessary parameters.[1] The final stage of the formal validation section of the study included: (1) the testing of the model's reliability and (2) the comparison of the conformity between the output of the simulation model and the real world data. In Chapter Five, it was noted that functions fitted to

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[1] Parameters are variables in the model which are not subject to experimentation. An example of a parameter is the matrix $P(C_{ij})$ denoting the initial probabilities for selecting channels. (See Chapter Three).

the replicated data indicated that the model is reliable; that is, the model's output is independent of the particular sequence of random numbers used to drive the model. Next, the model's output was compared to the real world for "goodness of fit." The Burgess experiments (1968) were the benchmark studies. Although the simulated results did not precisely replicate the findings, the data in general did agree and conform to the Burgess laboratory results. The model does appear to be a reasonably valid representation of the real world.

Another important function in the model's operation, was the inclusion of a linear learning model as suggested by Bush and Mosteller (1955). This learning function was used to alter the selections of behavior (message and channel selections). Its adoption was consistent with experimental evidence in the literature (Luce, 1960). However, the base rate of change alpha was set at two per cent by extrapolation into the structural paradigm. To determine the model's sensitivity to an incorrect specification for this base rate, two runs were made generating time paths for (1) eliminating the learning function and (2) changing the base rate to five per cent. An initial visual comparison of not including the learning function indicated that a linear function could describe the output, and deviations from this linear function would be as great at the end of 800 trials as it was during the first 100 trials. Additionally, the slope of the data points indicated that no improvement in solution rates had been achieved.

Changing the base rate to five per cent produced a time path which clearly resembled a power function. However, the rate of change appeared to be a direct function of the initial rate. It was concluded that a selection of a base rate different than two per cent would affect the output only in the determination of the onset of a steady state. The relationship of these steady states between networks would still remain constant. This tended to increase the author's confidence in the model. In summary, the validation phase led to increased confidence in the model.

Conclusions from the Experimental Phase of the Study

The findings on the productivity variable indicate that, in the long run, the fewer the levels of hierarchy in communication networks, the sooner optimal levels of productivity are achieved. It appears from a visual comparison that the All-Channel and Wheel networks reach more efficient task performance levels sooner than Circle networks. Also, the questions about productivity investigated by previous studies have been premature in their findings. The data produced in this study question the exclusion, in earlier studies, of the long run effects of learning and reinforcement in CNE.

The findings on time to solution for the networks studied indicate that transition stages are evident for both Circle and All-

Channel networks. Further, the transition stage is of shorter duration for All-Channel networks. Minimal times to solution are achieved sooner by the lower level hierarchical networks.

The findings on the solution rates indicate a substantial difference in performance between networks characterized by single and multiple levels of hierarchy. Optimal solution rates are reached sooner under All-Channel networks than Circle networks. This finding partially supports the Burgess (1968) hypothesis that Wheels achieve maximum solution rates sooner than Circles. Only during long-term experimental conditions--recognizing and employing learning and reinforcement--do these findings become evident.

The results of the total replications and experiment indicate that the behavior exhibited in communication networks is a very lawful phenomenon which can be described precisely by a power function of the form $Y = AX^B$. Additionally, the communication structure affects the behavior of groups indirectly, by either handicapping or facilitating the group members in their attempts to organize themselves for efficient task performance. There is, for example, a difference in the networks with regard to the time it takes to reach a steady state.

In this connection, certain structural characteristics stand out. The Circle network produces a communication pattern, which besides requiring a relay system of some sort for information transferral, permits the group members to communicate with their respective "neighbors". Such a structure increases the possibility of duplicate and non-task behavior. In the absence of behavior consequences in the real world, this is precisely what happens. Although it would seem that this type of duplication would be more prevalent in All-Channel networks, both the evidence in real world experiments and the simulated data demonstrate that systems of relaying information do not develop but direct communication among all members develops.

Possible Future Research

Future work on the model can take several directions. The two classes these directions may take are (1) changes in the model, and (2) further work with the present model. Suggestions for changes in the model are presented first.

Before adding additional complexity to the model, an attempt should be made to reduce the present complexity. The purpose of modeling may be defeated by adding additional complexity. The model may become too complex to be understood. Dutton and Starbuch (1971) caution model builders that the purpose of modeling is to be able to examine the real world through the use of a simplified model of the process--such that the model is complicated enough to deal with reality, but not so complicated that an understanding of reality is impeded.

Sensitivity analysis is used to reduce the complexity of the model's specifications. It indicates the changes in output resulting from changes in the model. If changes in the model do not affect the output, then the model may be simplified. Some suggested changes in the model may be (1) the replacement of values generated by a probability distribution with one or two parameters, or (2) elimination of some model components. An example of the former approach may be found in response to requests. In Chapter Three the response to requests was partially determined by the value of a random variable. (See Explanation of RNS_{ij}.) The determination of responses was also a function of prior experience. Rather than permitting changes in this probability distribution to occur with experience, a parameter value may be substituted such that the variance within an experimental run may be reduced.

In the latter approach, simplification of the model is accomplished by eliminating component relationships. For example: the correction factor, V_r, used to reduce sending data messages through the same channel during a trial could be eliminated completely.

Model construction calls for the general principle of economy; that is, if a simple explanation will do, it is unnecessary to seek a complex one. Once the present complexity of the model has been reduced, there are several approaches to increasing the scope of this study by changing the model.

In this study, one simple task was employed. It has been suggested that more complex tasks (see Shaw, 1964) produced different results for CNE. Although the model would require substantial modifications to adapt to the complex problem described in Chapter Two, it is possible to adapt the current model to a series of simple tasks. By complicating the total task such that successful performance would require a group to solve two or more stages in a complex simple problem would achieve this conversion. Thus, without changing the model, the effects of learning and reinforcement can be investigated for various network's productivity. Tasks of this nature are commonly found in real world situations.

Another modification which can be made is to remove restrictions for transfer of information. Currently, the model requires transactions for all members to take place at one time. Most CNE using simple problems did not have this restriction. Random selection of a network member to initiate information transferral one or more times during a trial can be included within the model. This procedure would result in unequal interaction rates, and should cause emergent patterns of organization to take form more quickly.

One possible refinement in the model is to increase the size of the network membership beyond the present four members. Increasing the size of the group requires no changes in the model's interrelationships. The range and domain for the arrays tracking the solution progress will have to be enlarged along with the parameter values for selecting messages and channels ($P(A_{ij})$ and $P(C_{ij})$). However, the communications patterns within the group may cause problems. Morrissette and Vannoy (1966) pointed out that the symbol-identification task, originally developed for the study of a five-man group, cannot be used to study larger size groups without substantially changing its difficulty by some unknown degree. Further, McWhinney (1964) attempted to increase the size of the communication network in his simulation study. His findings were in contradiction to the accepted view that the opening of communication channels provides too much complication for effective group learning. His runs with larger simulated groups pointed to a different learning problem which would face the larger real group. The variation in performance between smaller and larger groups does not increase at the same rate. Thus, as group size increases, the percentage improvement diminishes, weakening the connection between adopting an appropriate organization and selection behaviors. It was suggested that the probable fault lay in permitting the simulated subjects equal propensity to generate actions. In future studies this could be corrected by introducing a J distribution of initiations of actions such as Stephan and Mischler (1952) have observed in group behavior.

In this study, no attempt was made to interfere with the operation of the networks in mid-run or to change the composition of the groups. To determine if structural constraints are solely responsible for improvement or changes in solution rates, the network can be changed after some period of time in the task setting. For example, at the beginning of a problem session, a group can be arranged as a Circle network, then changed to an All-Channel network. It is expected that an immediate deterioration in performance will result after which the variability in the group's behavior should be reduced. If this is the case, structural constraints can be viewed as the determinant of productivity. Combinations of changes can be tried in any sequence. The minor change in the model to permit this investigation would require only a change in the probabilities for channel selection ($P(C_{ij})$). This probability distribution should be set equal to the initial conditions for the network to which the change is to be made.

A variation on the above recommendation would be to permit one group member to leave the network. No provisions for member entrance and exit from the network were included in this study. A further refinement in the model is to include turnover. In the real world, this condition may be prevalent. To observe changes in productivity as a result of turnover, the model can accommodate this option at any time be resetting the probability distributions for one or more network members to the initial conditions. By examining the behavior of the group before and after an individual leaves the network, the effects of disruption due to turnover could be analyzed.

Weick (1969) suggests that the behavior of any group should be examined in the context of its organizational setting. An ambitious goal of future research is to provide a communications network with an organization setting. Weick stated that an organization may be defined as a group of groups. It appears reasonable to arrange several communication networks as an organization by connecting them such that the solution of a task is group-dependent. This process would be very much like the two or more stage task for one network but may require interactions not yet specified in the model. By developing an organizational model, the effects of varying combinations of hierarchical networks on productivity could be examined. Ultimately, the objective of this research is to contribute to behavioral theories of organization which are concerned with information and communication transferral.

Summary

The first objective of this study was to demonstrate the feasibility and desirability of the computer simulation approach to socio-psychological research. The feasibility of the computer simulation approach was demonstrated by the construction of a model of the communication networks which successfully passed a number of validation requirements. The desirability of this approach was demonstrated by the ease of experimentation on the model. As an experimental tool, the computer simulation model can be manipulated in many ways. Further evidence of the desirability and versatility of the simulation approach was offered in the section on future research.

The validation phase in socio-psychological simulations was discussed. It should be clear that the need to validate should influence the entire research effort. In Chapter Four, it was indicated that the choice of the output variables was dictated by those required for the validation phase. Due to the significance of verification and validation needs in simulation studies, every stage of planning for these experiments should be affected by these requirements.

The results of the experimental phase of the study support the hypothesis that, in the long run, All-Channel networks achieve equal rates of productivity as do Circle networks. Further, these rates are reached sooner by lower level hierarchies such as the All-Channel network. Lastly, the behavior of task solution within these communication networks can be described by the general power function $Y = AX^B$.

Within the limitations cited in Chapter One, the computer simulation of socio-psychological systems was shown to be a desirable and feasible approach. However, several problems still exist; validation and data analysis are the most persistent. To realize the full potential of the computer simulation approach, further improvements in statistical methodology must be made.

BIBLIOGRAPHY

Abelson, Robert P., "Simulation of Social Behavior," Handbook of Social Psychology. Vol. II, Edited by B. Lindzey and E. Aronson. (2nd ed.) Reading, Mass.: Addison-Wesley Publishing Company, 1968.

Baker, Helen, Ballantine, J. W. and True, J. M. Transmitting Information Through Management and Union Channels. Princeton: Princeton Univ. Dept. of Economic and Social Institutions. 1949.

Bales, Robert F., "Interaction Process Analysis." International Encyclopedia of the Social Sciences. Vol. VII, 1968.

Bales, Robert F. and Strodtbeck, T. M. "Channels of Communication in Small Groups." American Sociological Review, 16, 1951. pp. 461-468.

Bavelas, Alex, "Communication Patterns in Task-Oriented Groups." Journal of the Acoustical Society of America, 22, 1950, pp. 725-730.

Burgess, Robert L., "Communication Networks: An Experimental Reevaluation." Journal of Experimental Social Psychology, 4, 1968, pp. 324-337.

Burgess, Robert L., "An Experimental and Mathematical Analysis of Group Behavior within Restricted Networks," Journal of Experimental Social Psychology, 4, 1968, pp. 338-349.

Bush, Robert R., and Mosteller, Fred, Stochastic Models for Learning, New York: Wiley, 1955.

Christie, Louis S., "Organization and information handling in task groups," Journal of Operations Research Society of America, 2, 1954, pp. 188-196.

Christie, L. S., Luce, R., and Macy, J., Jr. "Communication and Learning in Task Oriented Groups," Technical Report, 231. Cambridge, Massachusetts Institute of Technology, Research Laboratory of Electronics, 1952.

Cohen, Arthur, M., "Changing Small Group Communication Networks," Administrative Science Quarterly, 6, 1962, pp. 443-462.

Cohen, Arthur M., Bennis, Warren G., and Wolkon, George H., "The Effects of Continued Practice on the Behaviors of Problem-Solving Groups." Sociometry, 25, 1962, pp. 416-431.

Collins, Barry E., and Raven, Bertram H., "Group Structure: Attraction, Coalitions, Communication, and Power." Handbook of Social Psychology. Edited by G. Lindzey and E. Aronson. (2nd ed.) Reading, Mass.: Addison-Wesley Publishing Company, 1969.

Conway, R. W.; Johnson, B. M.; and Maxwell, W. L. "Some Problems of Digital Systems Simulation." Management Science, Vol. VI. 1959. pp. 92-100.

Cyert, R. M. and March, J. G. A Behavioral Theory of the Firm. Englewood Cliffs, New Jersey: Prentice Hall, 1963.

Davis, James H., Group Performance. Reading Mass.: Addison-Wesley Publishing Company, 1969.

Dutton, John M. "Finding Charlie's Run-Time Estimator," Computer Simulation of Human Behavior. Edited by J. Dutton and W. Starbuck. New York: Wiley, 1971.

Dutton, John M., and Briggs, Warren G. "Simulation Model Construction." Computer Simulation of Human Behavior. Edited by J. Dutton and W. Starbuck, New York: Wiley, 1971.

Dutton, John M. and Starbuck, William H. Computer Simulation of Human Behavior. New York: Wiley, 1971.

Egerman, Karl, "Effects of Team Arrangement on Team Performance: A Learning-Theoretic Analysis," Journal of Personality and Social Psychology, 3, 1966, pp. 541-550.

Flament, C., Application of Graph Theory to Group Structure. Englewood Cliffs, New Jersey: Prentice-Hall, 1963.

Glanzer, M., and Glaser, Robert, "Techniques for the Study of Group Structure and Behavior: II. Empirical Studies of the Effects of Structure in Small Groups." Psychological Bulletin, 58, 1961, pp. 1-27.

Glaser, Robert and Klaus, David J. "A Reinforcement Analysis of Group Performance." Psychological Monographs, no. 621, 1966.

Greeno, James G., Elementary Theoretical Psychology. Reading, Mass.: Addison-Wesley Publishing Company, 1968.

Greenspoon, Joel, "The Reinforcement Effect of Two Spoken Sounds in the Frequency of Two Responses." American Journal of Psychology, Vol. LXVIII, 1955, pp. 409-416.

Guetzkow, Harold, "Communications in Organizations." In Handbook of Organizations, J. March, ed. Chicago: Rand McNally and Company. 1965.

Guetzkow, Harold, and Dill, William R., "Factors in the Organizational Development of Task-Oriented Groups." Sociometry, 20, 1957, pp. 175-204.

Guetzkow, Harold and Simon, Herbert A., "The Impact of Certain Communication Nets upon Organization and Performance in Task-Oriented Groups." Management Science, 1, 1955, pp. 233-250.

Hall, Calvin and Lindzey, Gardiner, "The Relevence of Freudian Psychology and Related Viewpoints for the Social Sciences." The Handbook of Social Psychology. 2nd ed. Reading, Mass.: Addison-Wesley Publishing Company, 1968.

Hare, A. Paul, Handbook of Small Group Research. New York: Free Press, 1962.

Hare, A. Paul, Borgatta, Edward F. and Bales, Robert F., Small Groups: Studies in Social Interaction. New York: Knopf, 1955.

Heise, George A. and Miller, G., "Problem Solving by Small Groups using Various Communication Nets." Journal of Abnormal and Social Psychology. 46, 1951, pp. 327-335.

Helson, H. "Adaptation Level as a Basis for a Quantitative Theory of Frames of Reference." Psychological Review, 55, 1948, pp. 297-313.

Homans, George, Social Behavior: Its Elementary Forms. New York: Harcourt Brace, 1961.

Homans, George, The Human Group. New York: Harcourt, Brace, 1950.

Johnston, John, Econometric Methods. New York: McGraw Hill Book, Inc., 1963.

Kendall, M. G. and Stuart, A., The Advanced Theory of Statistics. Vol. III, New York: Hafner Publishing Co. 1966.

Kiesler, Charles A. Conformity, Reading, Mass.: Addison-Wesley Publishing Company. 1969.

Lanzetta, J. T. and Roby, T. B., "Group Learning and Communication as a Function of Task and Structure Demands." Journal of Abnormal and Social Psychology. 55, 1957, pp. 121-131.

Laughery, Kenneth R. and Gregg, Lee W. "Simulation of Human Problem-Solving Behavior." Psychometrica, 27, 1962, pp. 265-282.

Lawson, Reed, "Reinforced and Non-Reinforced Four Man Communication Nets." Psychological Reports. 14, 1964, pp. 287-296.

Leavitt, Harold J., "Some Effects of Certain Communication Patterns on Group Performance." Journal of Abnormal and Social Psychology. 46, 1951, pp. 38-50.

Leavitt, Harold J. and Knight, K. E., "Most Efficient Solutions to Communication Networks: Empirical versus Analytical Search." Sociometry. 26, 1963, pp. 260-267.

Leavitt, Harold J. and Mueller, R. A. H., "Some Effects of Feedback on Communication." Human Relations, 4, 1951, pp. 401-410.

Luce, R. Duncan, ed. Developments in Mathematical Psychology. Free Press, Glencoe, Ill. 1960.

Luce, R. Duncan, Macy, J. Jr., and Hay, "Information Flow in Task-Oriented Groups." Technical Report No. 264. Massachusetts Institute of Technology, Research Laboratory of Electronics. Cambridge, Mass.: 1954.

Marshall, Wayne S., "Simulating the Communication Networks Experiments." Management Science, 13, 1966, pp. 656-665.

McWhinney, William H., "Computer Simulation of the Communication Network Experiments." Behavioral Science, 1964, pp. 80-84.

Miller, George A. Language and Communication. New York: McGraw Hill, 1951.

Morrissette, J. O. and Vannoy, J.. "Revision of a Mathematically Defined Task to Study Group Performance." Technical Report No. AMTRL-TR-66-68. Aerospace Medical Research Laboratory. 1966.

Mulder, Mauk. "Group Structure and Group Performance." Acta Psycholica, 16, 1959. pp. 356-402.

Naylor, Thomas and Finger, J. M. "Verification of Computer Simulation Models." Management Science, XIV, No. 2, 1967, pp. 92-101.

Osgood, Charles, Methods and Theory in Experimental Psychology. New York: Oxford University Press, 1953.

Schein, Edgar H. "The Development of Organization in Small Problem Solving Groups." Final Report on Sloan Project No. 134. Massachusetts Institute of Technology Cambridge: 1958.

Raino, K. "Social Interaction as a Stochastic Learning Process." European Journal of Sociology, 6, 1965, pp. 66-68.

Shaw, Marvin E. "Group Structure and the Behavior of Individuals in Small Groups. Journal of Psychology, 38, 1954. pp. 139-149.

Shaw, Marvin E. "Some Effects of Irrelevant Information in Communication Nets." Journal of Social Psychology, 47, 1958. pp. 33-37.

Shaw, Marvin E. "Some Factors Influencing the Use of Information in Small Groups." Psychological Reports; 8, 1961. pp. 187-198.

Shaw, Marvin E. "Communication Networks." In. L. Berkowitz ed. Advances In Experimental Social Psychology. Vol. 1, New York: Academic Press. pp. 111-147.

Shaw, Marvin and Rothschild, G. H., "Some Effects of Prolonged Experience in Communication Nets." Journal of Applied Psychology, 40, 1956. pp. 281-286.

Sherif, Muzafer and Hovland, C. I. Social Judgement. New Haven, Conn.: Yale Press, 1961.

Staats, A. W. and Staats, C. K. Complex Human Behavior: A Systematic Extension of Learning Principles. New York: Holt, 1964.

Stephan, F. F. and Mischler, E. G. "The Distribution of Participation in Small Groups: and Exponential Approximation." American Sociological Review. 17, 1952. pp. 598-608.

Stogdill, Robert M., Individual Behavior and Group Achievement: a Theory. New York: Oxford University Press. 1959.

Swanson, G. E. "On Explanations of Social Interaction." Sociometry. 28, 1965. pp. 101-123.

Tapp, Jack, Reinforcement and Behavior. New York: Academic Press, 1969.

Thibaut, John W. and Kelley, Harold H., The Social Psychology of Groups. New York: John Wiley and Son, Inc. 1959.

Tresselt, M. E. "The Influence of Amount of Practice upon the Formation of a Scale of Judgement." Journal of Experimental Psychology, 37, 1947. pp. 251-260.

Van Horn, Richard L., "The Problems of Validation." Paper presented at meeting of The Institute of Management Sciences, Oct. 1968.

Van Horn, Richard L., "Validation of Simulation Results." Management Science, 17, 1971. pp. 247-258.

Von Foerster, H. and Zopf, G. W. eds. Principles of Self-Organization. New York: Pergamon Press, 1961.

Weick, Karl, The Social Psychology of Organizing. Reading, Mass.: Addison-Wesley Publishing Company, 1969.

Willis, R. H. and Hale, J. F. "Dyadic Interactions as a Function of Amount of Feedback and Instructional Orientation." Human Relations, 16, 1963. pp. 149-160.

APPENDIX A

COMPUTER PROGRAM OF SIMULATION MODEL

This appendix contains the computerized form of the simulation model. The program was written in Fortran IV for a CDC 3300.

OS3 FORTRAN VERSION 3.1.0   04/06/73 0158

```
       DEFINE COMMON
       COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
      $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
      $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
      $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
      $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
      $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
       REAL MEMMAT
       REAL MEVEC
       REAL INMATSN
       REAL INMATRC
       INTEGER OUT
       END
```

```
      PROGRAM MAIN
C     THIS IS CIRCLE (WITH DATRTRN,REQHLD)LEARNED RETURNS
C     TO REQUESTS USING -3-16-73
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      CALL EQUIP (12,8HDATA1    )
      REWIND 12
      READ (12,620) OUT
      READ (12,630) ((MEMMAT(I,J),J=1,4),I=1,4)
      READ (12,630) ((MEVEC(I,J),J=1,4),I=1,4)
      READ (12,640) ((ITEST(I,J),J=1,3),I=1,2)
      READ (12,650) ((IPKMAN(I,J),I=1,4),J=1,3)
      READ (12,660) (DSNDVEC(J),J=1,4)
      READ (12,670) ALPHA
      READ (12,680) ((KTEST(I,J),J=1,4),I=1,11)
      READ (12,690) MRND,NTRL
      READ (12,700)((KNOWANS(J,K),J=1,4),K=1,4)
      READ(12,710)((REQHLD(J,K),J=1,4),K=1,2)
      CALL UNEQUIP (12)
      ICODE = 1
      DUMMY = RNOG(1)
      TMCLK(1) = 0.0
C     BEGIN TRIAL
      DO 610 ITRIAL=1,NTRL
      TMCLK(1) = TMCLK(1)+1.0
      CALL ZRAYS (2)
C     BEGIN ROUND
      DO 580 IROUND=1,MRND
      IF (IROUND.EQ.1) GO TO 20
      CALL ZRAYS (1)
      ANS = 0.0
      DO 10 L=1,4
      ANS = ANVEC(5,L)+ANS
 10   CONTINUE
      IF (ANS.EQ.4.0) 590,20
 20   TMCLK(2) = TMCLK(2)+1.0
      DO 560 J=1,4
      KSUB = 0
C           DOES MAN HAVE ANSWER
      IF (ANVEC(5,J).LT.1.) 30,330
 30   TAN1 = 0.0
      TAN2 = 0.0
      TAN1 = .99
      TAN2 = .99
C           ANY DATA REQUESTS OUTSTANDING IN NEANS
      CALL SEARCH (1,KSUB,J)
      IF (KSUB.EQ.0) 70,35
   35 R=RNOG(2)
      R=R/100.
```

```
      IF(R.LT.REQHLD(J,1))40,70
C           DATA WAS SENT TO KSUB LAST ROUND
 40   IF (LSTRND1(J,KSUB).GE.1) CALL NEWDAT (J,KSUB,2,AMEVEC)
      R = RNOG(2)
      R = R/100.
      IF (R.LE.TAN1) 50,70
 50   CALL MESSUP (KSUB,J,2,1,1)
      GO TO 560
 60   CALL MESSUP (KSUB,J,2,2,1)
      GO TO 560
C           ANY ANSWER REQUESTS
 70   CALL SEARCH (2,KSUB,J)
      IF (KSUB.EQ.0) 90,75
   75 R=RNOG(2)
      R=R/100.
      IF(R.LT.REQHLD(J,2))80,90
 80   IF (LSTRND1(J,KSUB).GE.1) CALL NEWDAT (J,KSUB,3,AMEVEC)
      R = RNOG(2)
      R = R/100.
      IF (R.LE.TAN2) 60,90
C           SELECT MAN
 90   R = RNOG(4)
      R = R/10000.
      DO 100 I=1,4
      L = I
      IF (R.LE.MEMMAT(J,I)) 110,100
 100  CONTINUE
 110  KSUB = L
C           SELECT MESSAGE
 120  R = RNOG(4)
      R = R/10000.
      DO 130 L=1,4
      I = L
      IF (R.GE.MEVEC(I,J)) 130,140
 130  CONTINUE
C           CANNOT REQUEST A  (SEND ANSWER ) FIRST ROUND
 140  IF (THCLK(2).EQ.1.) 150,160
 150  IF (I.EQ.3) 120,160
 160  IF (I.EQ.4) 165,180
  165 IF(KWAIT2(J).EQ.2)120,170
 170  CALL MESSUP (KSUB,J,5,0,5)
      KWAIT1(J,1)=1
      GO TO 560
 180  IF (I.EQ.1) 190,260
 190  IF (LSTRND1(J,KSUB).GE.1) 200,210
C           IS THERE ANY NEW DATA SINCE LAST RECEIVED
 200  CALL NEWDAT (J,KSUB,1,AMEVEC)
      IF (AMEVEC.EQ.0.0)220,210
 210  CALL MESSUP (KSUB,J,1,0,1)
      GO TO 560
 220  R = RNOG(4)
      R = R/10000.
      IF (R.LE.AMEVEC) 230,90
 230  CALL MESSUP (KSUB,J,1,0,1)
      GO TO 560
C           DID NOT CHOOSE TO SEND DATA TO THIS MAN BECAUSE IT HAS SENT
C           THIS TRIAL
 260  IF (I.EQ.2) 270,290
C           HAS THIS DATA BEEN SENT LAST ROUND
```

```
 270   IF (LSTRND1(J,KSUB).GE.1) 120,280
 280   CALL MESSUP (KSUB,J,3,1,3)
       GO TO 560
 290   IF (I.EQ.3) 300,310
 300   CALL MESSUP (KSUB,J,4,2,4)
       GO TO 560
 310   IF (I.EQ.4) 315,330
  315  IF(KWAIT2(J).EQ.2)120,320
 320   CALL MESSUP (KSUB,J,5,0,5)
       KWAIT1(J,1)=1
       GO TO 560
C            MAN HAS ANSWER LOOKING FOR ANOTHER TO SEND IT
  330  NUM=0
       DO 335 K=1,4
       IF(KNOWANS(J,K).NE.0) GO TO 335
       NUM=NUM+1
  335  CONTINUE
       IF(NUM.EQ.0) GO TO 560
       CALL SEARCH (2,KSUB,J)
       IF(KSUB.EQ.0)GO TO 400
       IF(NUM.EQ.1)GO TO 350
  340  CALL MESSUP(KSUB,J,2,2,2)
       KNOWANS(J,KSUB)=2
       GO TO 560
  350  IF(KNOWANS(J,KSUB).EQ.0)GO TO 340
       DO 360 K=1,4
       IF(KNOWANS(J,K).GT.0) GO TO 360
       KSUB=K
  360  CONTINUE
       CALL MESSUP(KSUB,J,1,0,2)
       KNOWANS(J,KSUB)=2
       GO TO 560
  400  IF(NUM.EQ.1) GO TO420
       CALL ANSERCH(J,KSUB)
  410  CALL MESSUP(KSUB,J,1,0,2)
       KNOWANS(J,KSUB)=2
       GO TO 560
  420  DO 430 K=1,4
       IF(KNOWANS(J,K).GT.0)GO TO 430
       KSUB=K
  430  CONTINUE
       GO TO 410
 560   CONTINUE
C            END OF ROUND , FILL CUMANS
       DO 570 M=1,4
       J = M
       IF(ANSHLD(5,J).EQ.1.)CUMANS(J) = CUMANS(J)+1.
 570   CONTINUE
 580   CONTINUE
 590   CALL PRINT (0,0,0,0,0,1,0,0,0,0)
       JTRIAL=ITRIAL/20
       JTRIAL=ITRIAL-20*JTRIAL
       IF(JTRIAL.EQ.0)CALL PRINT(1,1,0,0,0,0,0,0,0,0)
       IF (TMCLK(2).LT.TMCLK(3)) 600,610
 600   CALL LRNER
 610   CONTINUE
       STOP
C
C
```

```
620   FORMAT  (I2)
630   FORMAT  (8F7.4)
640   FORMAT  (6I5)
650   FORMAT  (12I3)
660   FORMAT  (4F5.2)
670   FORMAT  (F5.2)
680   FORMAT  (18I3)
690   FORMAT  (2I7)
 700  FORMAT(16I2)
 710  FORMAT(8F4.2)
      END
```

```
      SUBROUTINE SEARCH (II,KSUB,JF)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLO(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      DIMENSION HLD(4), VCK(3)
      KSUB = 0
      DO 20 K=1,4
      IF (NEANS2(II,JF,K).GT.0) 10,20
 10   KSUB = K
 20   CONTINUE
      IF (KSUB.EQ.0) 290,30
 30   LEQT = 0
      DO 50 K=1,4
      LEQ(K) = 0
      IF (K.EQ.JF) GO TO 50
      IF (NEANS2(II,JF,K).GT.0) 40,50
 40   LEQ(K) = 1
      KM = K
      LEQT = LEQT+1
 50   CONTINUE
C           DETERMINE INTERACTION RATES OF THOSE WHO ONLY REQUEST ANS OR
      IF (LEQT.EQ.1) 60,70
 60   KSUB = KM
 70   IF (LEQT.EQ.1) GO TO 290
      L = 1
      DO 100 I=1,4
      IF (LEQ(I).EQ.1) 80,100
 80   IF (MEMMAT(JF,I).EQ.0.0) 100,90
 90   HLD(L) = MEMMAT(JF,I)
      VCK(L) = I
      L = L+1
 100  CONTINUE
      IF (LEQT.EQ.3) GO TO 130
C     COMPARISON OF INTERACTION RATES FOR TWO REQUESTS
      V = 0.0
      V = HLD(2)-HLD(1)
      IF (.50-V) 110,260,120
 110  KSUB = VCK(2)
      GO TO 230
 120  KSUB = VCK(1)
      GO TO 230
 130  IF (HLD(1).EQ.HLD(2).AND.HLD(1).EQ.HLD(3)) GO TO 180
      IF (HLD(1)+.33.GT.HLD(2)) 140,190
 140  IF (HLD(1)+.66.GT.HLD(3)) 150,160
 150  IF (HLD(1)+.33.EQ.HLD(2)) 180,160
 160  IF (HLD(1)+.66.EQ.HLD(3)) 180,170
 170  KSUB = VCK(1)
      GO TO 230
 180  GO TO 260
 190  IF (HLD(2)+.33.EQ.HLD(3)) 260,200
```

```
200   IF (HLD(2)+.33.GT.HLD(3)) 210,220
210   KSUB = VCK(2)
      GO TO 230
220   KSUB = VCK(3)
      GO TO 230
230   DO 240 K=1,4
      HLD(K) = 0.0
240   CONTINUE
      DO 250 L=1,3
      VCK(L) = 0.0
250   CONTINUE
      GO TO 290
260   IR = RNOG(2)
      MM = 0
      DO 270 I=1,3
      IF (IR.GT.ITEST(LEQT-1,I)) 270,280
270   CONTINUE
280   MM = I
      KSUB = IPKMAN(JF,MM)
290   RETURN
      END
```

```
      SUBROUTINE NEWDAT (J,KSUB,KPT1,AMEVEC)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),OSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      AMEVEC = 0.0
      BB = 0.
      DO 10 I=1,5
10    BB = ANSHLD(I,KSUB)+BB
      BO = 0.0
      DO 20 I=1,5
20    BO = ANVEC(I,KSUB)+BO
      IF(BB.GT.BO)40,30
   40 CALL DATSND (J,KSUB,KPT1,AMEVEC,TAN1,TAN2)
30    RETURN
      END
```

```
      SUBROUTINE NEWDAT (J,KSUB,KPT1,AMEVEC)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      AMEVEC = 0.0
      BB = 0.
      DO 10 I=1,5
10    BB = ANSHLD(I,KSUB)+BB
      BO = 0.0
      DO 20 I=1,5
20    BO = ANVEC(I,KSUB)+BO
      IF(BB.GT.BO)40,30
   40 CALL DATSND (J,KSUB,KPT1,AMEVEC,TAN1,TAN2)
30    RETURN
      END
```

```
      SUBROUTINE DATSNO (J,KSUB,IKEY,AMEVEC,TAN1,TAN2)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRNO1(4,4),LO(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLO(2,2),LSTRNO2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      TAN1 = .80
      TAN2 = .20
      GO TO (10,20,30), IKEY
10    IVAL = DATASNT(J,KSUB)
      IF(IVAL.GT.4)IVAL = 4
      AMEVEC = .80-(MEVEC(1,KSUB)*DSNDVEC(IVAL))
      GO TO 40
20    IVAL = DATASNT(J,KSUB)
      IF(IVAL.GT.4)IVAL = 4
      TAN1 = TAN1-(TAN1*DSNDVEC(IVAL))
      GO TO 40
30    IVAL = DATASNT(J,KSUB)
      IF(IVAL.GT.4)IVAL = 4
      TAN2 = TAN2-(TAN2*DSNDVEC(IVAL))
      GO TO 40
40    RETURN
      END
```

```
      SUBROUTINE MESSUP (KSUB,JM,KPT,II,IB)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRNO1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRNO2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNOVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      INMATSN(IB,JM,KSUB) = INMATSN(IB,JM,KSUB)+1.0
      INMATSN(IB,JM,5) = 0.0
      DO 20 K=1,4
      INMATSN(IB,JM,5) = INMATSN(IB,JM,5)+INMATSN(IB,JM,K)
20    CONTINUE
      INMATSN(6,JM,KSUB) = 0.0
      DO 30 I=1,5
      INMATSN(6,JM,KSUB) = INMATSN(6,JM,KSUB)+INMATSN(I,JM,KSUB)
30    CONTINUE
      CUMSNT(IB,JM,KSUB) = CUMSNT(IB,JM,KSUB)+1.
      CUMSNT(IB,JM,5) = 0.0
      DO 40 K=1,4
      CUMSNT(IB,JM,5) = CUMSNT(IB,JM,5)+CUMSNT(IB,JM,K)
40    CONTINUE
      CUMSNT(6,JM,KSUB) = 0.0
      DO 50 I=1,5
      CUMSNT(6,JM,KSUB) = CUMSNT(6,JM,KSUB)+CUMSNT(I,JM,KSUB)
50    CONTINUE
      IF (KPT.EQ.5) 150,60
60    INMATRC(IB,KSUB,JM) = INMATRC(IB,KSUB,JM)+1.
      INMATRC(IB,KSUB,5) = 0.0
      DO 70 K=1,4
      INMATRC(IB,KSUB,5) = INMATRC(IB,KSUB,5)+INMATRC(IB,KSUB,K)
70    CONTINUE
      INMATRC(5,KSUB,JM) = 0.0
      DO 80 I=1,4
      INMATRC(5,KSUB,JM) = INMATRC(5,KSUB,JM)+INMATRC(I,KSUB,JM)
80    CONTINUE
      CUMRCD(IB,JM,KSUB) = CUMRCD(IB,JM,KSUB)+1.
      CUMRCD(IB,KSUB,5) = 0.0
      DO 90 K=1,4
      CUMRCD(IB,KSUB,5) = CUMRCD(IB,KSUB,5)+CUMRCD(IB,KSUB,K)
90    CONTINUE
      CUMRCD(5,KSUB,JM) = 0.0
      DO 100 I=1,4
      CUMRCD(5,KSUB,JM) = CUMRCD(5,KSUB,JM)+CUMRCD(I,KSUB,JM)
100   CONTINUE
      IF (KPT.EQ.3) 110,120
110   NEANS1(II,KSUB,JM) = NEANS1(II,KSUB,JM)+1
      GO TO 150
120   IF (KPT.EQ.4) 130,140
130   NEANS1(2,KSUB,JM) = 1
      GO TO 150
140   LSTRNO2(JM,KSUB) = 1
      DATASNT(JM,KSUB) = DATASNT(JM,KSUB)+1.
      IF (KPT.LE.2) CALL TRANVEC (KSUB,1,JM)
```

```
      IF(KPT.EQ.2)145,150
  145 NEANS2(II,JM,KSUB) = NEANS2(II,JM,KSUB)-1
      DATRTRN(II,JM,1)=DATRTRN(II,JM,1)+1.0
 150  RETURN
      END
```

```
      SUBROUTINE TRANVEC (KSUB,KEY,J)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRNO1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRNO2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      GO TO (10), KEY
10    DO 20 I=1,4
      IF (KSUB.EQ.I) GO TO 20
      IF(ANVEC(I,J).GT.ANVEC(I,KSUB))ANSHLD(I,KSUB) = 1.
20    CONTINUE
      X = 0.0
      DO 30 I=1,4
30    X = ANSHLD(I,KSUB)+X
      IF (X.EQ.4.) 40,50
40    ANSHLD(5,KSUB) = 1.0
50    RETURN
      END
```

```
      SUBROUTINE ANSERCH (J,KSUB)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      DIMENSION HLD(4), VCK(3)
C           NO ANSWER HAS BEEN SENT , DETERMINE A KSUB
C           THERE IS ONLY ONE MAN TO SEND A MESSAGE
      IHLDR = 0
      DO 10 I=1,4
      IF (I.EQ.J) GO TO 10
      IF (MEMMAT(J,I).EQ.0.0) GO TO 10
      IHLDR = IHLDR+1
      KSUB = I
 10   CONTINUE
      IF (IHLDR.EQ.1) 230,20
 20   L = 1
      DO 40 I=1,4
      IF (MEMMAT(J,I).EQ.0.0) 40,30
 30   HLD(L) = MEMMAT(J,I)
      VCK(L) = I
      L = L+1
 40   CONTINUE
      IF (IHLDR.EQ.3) GO TO 70
      V = 0.0
      V = HLD(2)-HLD(1)
      IF (.50-V) 50,200,60
 50   KSUB = VCK(2)
      GO TO 170
 60   KSUB = VCK(1)
      GO TO 170
 70   IF (HLD(1).EQ.HLD(2).AND.HLD(1).EQ.HLD(3)) GO TO 120
      IF (HLD(1)+.33.GT.HLD(2)) 80,130
 80   IF (HLD(1)+.66.GT.HLD(3)) 90,100
 90   IF (HLD(1)+.33.EQ.HLD(2)) 120,100
 100  IF (HLD(1)+.66.EQ.HLD(3)) 120,110
 110  KSUB = VCK(1)
      GO TO 170
 120  GO TO 200
 130  IF (HLD(2)+.33.EQ.HLD(3)) 200,140
 140  IF (HLD(2)+.33.GT.HLD(3)) 150,160
 150  KSUB = VCK(2)
      GO TO 170
 160  KSUB = VCK(3)
      GO TO 170
 170  DO 180 K=1,4
      HLD(K) = 0.0
 180  CONTINUE
      DO 190 L=1,3
      VCK(L) = 0.0
 190  CONTINUE
```

```
      GO TO 230
200   IR = RNOG(2)
      MM = 0
      DO 210 I=1,3
      IF (IR.GT.ITEST(IHLDR-1,I)) 210,220
210   CONTINUE
220   MM = I
      KSUB = IPKMAN(J,MM)
230   RETURN
      END
```

```
      SUBROUTINE LRNER
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),OSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      DIMENSION IHN(4), IZEK(4), HLD(4), VCK(3)
      CALL INCNUM
      WRITE (OUT,610)
      DO 400 J=1,4
      ITEM = 0
      RV = 0.0
      LEQT = 0
      KV = 0
      VX = 0.0
      LS=0
      DO 25 I=1,5
      IF (I.EQ.2) GO TO 25
      IF (INMATSN(I,J,5).GT.VX) 10,20
10    RV = LS
      LEQT = LEQT+1
20    LS=LS+1
   25 CONTINUE
      IF(LEQT.EQ.0) GO TO 400
      IF (LEQT.EQ.1) 30,40
30    ITEM = RV
      GO TO 390
40    DO 50 I=1,4
      IHN(I) = 0
      IZEK(I) = 0
50    CONTINUE
      I = 1
      DO 60 L=1,5
      IF (L.EQ.2) GO TO 60
      IZEK(I) = INMATSN(L,J,5)
      KV = I
      IHN(I) = KV
      I = I+1
60    CONTINUE
      MM = 0
      IF (IZEK(1).GT.IZEK(2).AND.IZEK(1).GT.IZEK(3).AND.IZEK(1).GT.IZEK
     $(4)) 70,80
70    ITEM = IHN(1)
      GO TO 390
80    IF (IZEK(2).GT.IZEK(1).AND.IZEK(2).GT.IZEK(3).AND.IZEK(2).GT.IZEK
     $(4)) 90,100
90    ITEM = IHN(2)
      GO TO 390
100   IF (IZEK(3).GT.IZEK(1).AND.IZEK(3).GT.IZEK(2).AND.IZEK(3).GT.IZEK
     $(4)) 110,120
110   ITEM = IHN(3)
      GO TO 390
```

```
120  IF (IZEK(4).GT.IZEK(1).AND.IZEK(4).GT.IZEK(2).AND.IZEK(4).GT.IZEK
    $(3)) 130,140
130  ITEM = IHN(4)
     GO TO 390
140  IF (IZEK(1).EQ.IZEK(2).AND.IZEK(1).EQ.IZEK(3).AND.IZEK(1).EQ.IZEK
    $(4)) 150,160
150  MM = 11
     GO TO 360
160  IF (IZEK(1).EQ.IZEK(2).AND.IZEK(1).EQ.IZEK(3)) 170,180
170  MM = 7
     GO TO 360
180  IF (IZEK(1).EQ.IZEK(2).AND.IZEK(1).EQ.IZEK(4)) 190,200
190  MM = 10
     GO TO 360
200  IF (IZEK(1).EQ.IZEK(3).AND.IZEK(1).EQ.IZEK(4)) 210,220
210  MM = 9
     GO TO 360
220  IF (IZEK(1).EQ.IZEK(2)) 230,240
230  MM = 1
     GO TO 360
240  IF (IZEK(1).EQ.IZEK(3)) 250,260
250  MM = 4
     GO TO 360
260  IF (IZEK(1).EQ.IZEK(4)) 270,280
270  MM = 6
     GO TO 360
280  IF (IZEK(2).EQ.IZEK(3).AND.IZEK(2).EQ.IZEK(4)) 290,300
290  MM = 8
     GO TO 360
300  IF (IZEK(2).EQ.IZEK(3)) 310,320
310  MM = 2
     GO TO 360
320  IF (IZEK(2).EQ.IZEK(4)) 330,340
330  MM = 5
     GO TO 360
340  IF (IZEK(3).EQ.IZEK(4)) 350,360
350  MM = 3
360  IR = RNOG(2)
     DO 370 I=1,4
     IF (IR.GT.KTEST(MM,I)) 370,380
370  CONTINUE
380  ITEM = IHN(I)
390  ADD = 0.0
     ADD = MEVEC(1,J)
     IF(ITEM.GT.1)ADD = MEVEC(ITEM,J)-MEVEC(ITEM-1,J)
     ADD=-.02*ADD+ALPHA
     CALL MEVINCR (ITEM,J,ADD)
400  CONTINUE
     WRITE (OUT,620) ((MEVEC(L3,M3),M3=1,4),L3=1,4)
C           NOW FOR INTERACTION RATES
     DO 600 J=1,4
     LEQT = 0
     IWHO = 0
     RGST = 0.0
     DO 430 K=1,4
     IF (K.EQ.1.AND.INMATRC(5,J,K).EQ.0.0) 430,410
 410 IF(INMATRC(5,J,K).EQ.0.0) GO TO 430
     IF (INMATRC(5,J,K).GE.RGST) 420,430
420  RGST = INMATRC(5,J,K)
```

```
      IWHO = K
      LEQT = LEQT+1
  430 CONTINUE
      IF(LEQT.EQ.0) GO TO 600
      IF (LEQT.EQ.1) GO TO 590
      L = 1
      DO 440 I=1,4
      IF (INMATRC(5,J,I).EQ.0.0) GO TO 440
      HLD(L) = INMATRC(5,J,I)
      VCK(L) = I
      L = L+1
  440 CONTINUE
      IF (LEQT.EQ.3) GO TO 470
      IF (HLD(2)-HLD(1)) 460,560,450
  450 IWHO = VCK(2)
      GO TO 590
  460 IWHO = VCK(1)
      GO TO 590
  470 IF (HLD(1).EQ.HLD(2).AND.HLD(1).EQ.HLD(3)) GO TO 560
      IF (HLD(1).GT.HLD(2)) 480,510
  480 IF (HLD(1).GT.HLD(3)) 490,500
  490 IF (HLD(1).EQ.HLD(2)) 560,500
  500 IF (HLD(1).EQ.HLD(3)) 560,530
  510 IF (HLD(2).EQ.HLD(3)) 560,520
  520 IF (HLD(2).GT.HLD(3)) 540,550
  530 IWHO = VCK(1)
      GO TO 590
  540 IWHO = VCK(2)
      GO TO 590
  550 IWHO = VCK(3)
      GO TO 590
  560 IR = RNOG(2)
      IWHO = 0
      DO 570 K=1,3
      IF (IR.GT.ITEST(LEQT-1,K)) 570,580
  570 CONTINUE
  580 ITEM = K
      IWHO = IPKMAN(J,ITEM)
C     SET THE INDICATOR FOR STRUCTURE
  590 CALL MEMMINC (J,IWHO)
  600 CONTINUE
      WRITE (OUT,630) ((MEMMAT(L4,M4),M4=1,4),L4=1,4)
      RETURN
C
  610 FORMAT (≠ LEARNER≠)
  620 FORMAT (4F7.4)
  630 FORMAT (4F7.4)
      END
```

```
      SUBROUTINE MEVINCR (ITEM,J,ADD)
      INCLUDE COMMON
      COMMCN TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),MEANS1(2,4,4),MEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      DIMENSION TEMP(4)
C
      WRITE (OUT,60) (ITEM,J,ADD)
C      ITEM = ROW
C      J    = COLUMN
C      ADD  = AMCUNT OF INCREMENT
C
      DO 10 I=1,4
      TEMP(I) = MEVEC(I,J)
 10   CONTINUE
      GO TO (20,30,40,50), ITEM
 20   RATIO = MEVEC(4,J)-MEVEC(1,J)
      RATIO = (RATIO-ADD)/RATIO
      MEVEC(1,J) = MEVEC(1,J)+ADD
      MEVEC(2,J) = MEVEC(1,J)+(TEMP(2)-TEMP(1))*RATIO
      MEVEC(3,J) = MEVEC(2,J)+(TEMP(3)-TEMP(2))*RATIO
      RETURN
 30   RATIO = MEVEC(1,J)+MEVEC(4,J)-MEVEC(2,J)
      RATIO = (RATIO-ADD)/RATIO
      MEVEC(1,J) = MEVEC(1,J)*RATIO
      MEVEC(2,J) = MEVEC(1,J)+(TEMP(2)-TEMP(1))+ADD
      MEVEC(3,J) = MEVEC(2,J)+(TEMP(3)-TEMP(2))*RATIO
      RETURN
 40   RATIO = MEVEC(2,J)+MEVEC(4,J)-MEVEC(3,J)
      RATIO = (RATIO-ADD)/RATIO
      MEVEC(1,J) = MEVEC(1,J)*RATIO
      MEVEC(2,J) = MEVEC(1,J)+(TEMP(2)-TEMP(1))*RATIO
      MEVEC(3,J) = MEVEC(2,J)+(TEMP(3)-TEMP(2))+ADD
      RETURN
 50   RATIO = MEVEC(3,J)
      RATIO = (RATIC-ADD)/RATIO
      MEVEC(1,J) = MEVEC(1,J)*RATIO
      MEVEC(2,J) = MEVEC(1,J)+(TEMP(2)-TEMP(1))*RATIO
      MEVEC(3,J) = MEVEC(2,J)+(TEMP(3)-TEMP(2))*RATIO
      RETURN
C
 60   FORMAT (≠ ITEM IS≠,I3,2X,≠J IS≠,I3,2X,≠ADD=≠,F7.4)
      END
```

```
      SUBROUTINE MEMMINC (J,IWHO)
      INCLUDE COMMON
C     IND DENOTES WHICH CONFIGURATION IS BEING USED
C     IND=1 FOR CIRCLES; IND=2 FOR CONCOM
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      DADD = 0.0
      ADD = 0.0
      WRITE (OUT,240) (J,IWHO)
      CLDD = 0.0
C
C     IND=1,FOR CIRC;LES, IND=2 , FOR COMCONS
      IND = 1
      GO TO (10,30), IND
 10   IF (IWHO.GT.2) GO TO 20
      ADD = ((.98*MEMMAT(J,IWHO))+ALPHA)-MEMMAT(J,IWHO)
      MEMMAT(J,IWHO) = MEMMAT(J,IWHO)+ADD
      RETURN
 20   ADD = (MEMMAT(J,IWHO)-MEMMAT(J,IWHO-2))
      ADD = (.98*ADD)+ALPHA-ADD
      MEMMAT(J,IWHO-2) = MEMMAT(J,IWHO-2)-ADD
      RETURN
   30 GO TO (40,80,120,160)J
   40 IF(IWHO.EQ.2)OLDD=MEMMAT(1,2)
      IF(IWHO.EQ.3)OLDD=MEMMAT(1,3)-MEMMAT(1,2)
      IF(IWHO.EQ.4)OLDD=MEMMAT(1,4)-MEMMAT(1,3)
      ADD=(.98*OLDD)+ALPHA-OLDD
      RATIO=(OLDD-ADD)/OLDD
      GO TO (50,50,60,70)IWHO
   50 MEMMAT(1,1)=0.0
      MEMMAT(1,2)=MEMMAT(1,2)+ADD
      MEMMAT(1,3)=MEMMAT(1,2)+(OLDD*RATIO)+(.5*ADD)
      RETURN
   60 MEMMAT(1,1)=0.0
      MEMMAT(1,2)=MEMMAT(1,2)*RATIO+(.5*ADD)
      MEMMAT(1,3)=MEMMAT(1,2)+OLDD+ADD
      RETURN
   70 MEMMAT(1,1)=0.0
      MEMMAT(1,2)=MEMMAT(1,2)*RATIO+(.5*ADD)
      MEMMAT(1,3)=MEMMAT(1,2)+(OLDD*RATIO)+(.5*ADD)
      RETURN
   80 IF(IWHO.EQ.1)OLDD=MEMMAT(2,1)
      IF(IWHO.EQ.3)OLDD=MEMMAT(2,3)-MEMMAT(2,1)
      IF(IWHO.EQ.4)OLDD=MEMMAT(2,4)-MEMMAT(2,3)
      ADD=(.98*OLDD)+ALPHA-OLDD
      RATIO=(OLDD-ADD)/OLDD
      GO TO (90,100,100,110)IWHO
   90 MEMMAT(2,2)=0.0
      MEMMAT(2,1)=MEMMAT(2,1)+ADD
      MEMMAT(2,3)=MEMMAT(2,1)+OLDD*RATIO+(.5*ADD)
```

```
      RETURN
  100 MEMMAT(2,2)=0.0
      MEMMAT(2,1)=MEMMAT(2,1)*RATIO+(.5*ADD)
      MEMMAT(2,3)=MEMMAT(2,1)+OLDD+ADD
      RETURN
  110 MEMMAT(2,2)=0.0
      MEMMAT(2,1)=MEMMAT(2,1)*RATIO+(.5*ADD)
      MEMMAT(2,3)=MEMMAT(2,1)+(OLDD*RATIO)+(.5*ADD)
      RETURN
  120 IF(IWHO.EQ.1)OLDD=MEMMAT(3,1)
      IF(IWHO.EQ.2)OLDD=MEMMAT(3,2)-MEMMAT(3,1)
      IF(IWHO.EQ.4)OLDD=MEMMAT(3,4)-MEMMAT(3,2)
      ADD=(.98*OLDD)+ALPHA-OLDD
      RATIO=(OLDD-ADD)/OLDD
      GO TO (130,140,140,150)IWHO
  130 MEMMAT(3,3)=0.0
      MEMMAT(3,1)=MEMMAT(3,1)+ADD
      MEMMAT(3,2)=MEMMAT(3,1)+OLDD*RATIO+(.5*ADD)
      RETURN
  140 MEMMAT(3,3)=0.0
      MEMMAT(3,1)=MEMMAT(3,1)*RATIO+(.5*ADD)
      MEMMAT(3,2)=MEMMAT(3,1)+OLDD+ADD
      RETURN
  150 MEMMAT(3,3)=0.0
      MEMMAT(3,1)=MEMMAT(3,1)*RATIO+(.5*ADD)
      MEMMAT(3,2)=MEMMAT(3,1)+(OLDD*RATIO)+(.5*ADD)
      RETURN
  160 IF(IWHO.EQ.1)OLDD=MEMMAT(4,1)
      IF(IWHO.EQ.2)OLDD=MEMMAT(4,2)-MEMMAT(4,1)
      IF(IWHO.EQ.3)OLDD=MEMMAT(4,3)-MEMMAT(4,2)
      ADD=(.98*OLDD)+ALPHA-OLDD
      RATIO=(OLDD-ADD)/OLDD
      GO TO (170,180,190,190)IWHO
  170 MEMMAT(4,4)=0.0
      MEMMAT(4,1)=MEMMAT(4,1)+ADD
      MEMMAT(4,2)=MEMMAT(4,1)+(OLDD*RATIO)+(.5*ADD)
      RETURN
  180 MEMMAT(4,4)=0.0
      MEMMAT(4,1)=MEMMAT(4,1)*RATIO+(.5*ADD)
      MEMMAT(4,2)=MEMMAT(4,1)+OLDD+ADD
      RETURN
  190 MEMMAT(4,4)=0.0
      MEMMAT(4,1)=MEMMAT(4,1)*RATIO+(.5*ADD)
      MEMMAT(4,2)=MEMMAT(4,1)+(OLDD*RATIO)+(.5*ADD)
      RETURN
C
 240  FORMAT (≠ J EQUALS≠,I3,2X,≠IWHO EQUALS≠,I3,1X)
      END
```

```
      SUBROUTINE INCNUM
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRNO1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRNO2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNDVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      DO 20 J=1,4
      IF(DATRTRN(1,J,1).LT.DATRTRN(1,J,2))GO TO 10
      REQHLD(J,1)=REQHLD(J,1)+.02*(1-REQHLD(J,1))
   10 IF(DATRTRN(2,J,1).LT.DATRTRN(2,J,2))GO TO 100
      REQHLD(J,2)=REQHLD(J,2)+.005*(1-REQHLD(J,2))
   20 CONTINUE
  100 DO 200 J=1,4
      DO 200 K=1,2
      DO 200 I=1,2
      DATRTRN(I,J,K)=0.0
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ZRAYS (KPTR)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRND1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRND2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),DSNOVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),REQHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      GO TO (10,110), KPTR
C     UPDATE ANVEC
 10   DO 20 JN=1,4
      DO 20 I=1,5
      IF(ANSHLD(I,JN).GT.ANVEC(I,JN))ANVEC(I,JN) = ANSHLD(I,JN)
 20   CONTINUE
      DO 30 N=1,4
      X = 0.0
      DO 30 M=1,4
      X = ANVEC(M,N)+X
      IF(X.EQ.4.)ANVEC(5,N) = 1.0
 30   CONTINUE
      DO 40 I=1,5
      DO 40 JN=1,4
      ANSHLD(I,JN) = 0.0
 40   CONTINUE
      DO 50 K=1,4
      ANSHLD(K,K) = 1.0
 50   CONTINUE
C           ZERO OUT LSTRND2
      DO 60 JT=1,4
      DO 60 KSUB=1,4
      LSTRND1(JT,KSUB) = LSTRND2(JT,KSUB)
 60   CONTINUE
      DO 65 LL=1,4
      KWAIT2(LL)=KWAIT1(LL,1)+KWAIT1(LL,2)
      KWAIT1(LL,2)=KWAIT1(LL,1)
      KWAIT1(LL,1)=0
   65 CONTINUE
      DO 70 I=1,4
      DO 70 KSUB=1,4
      LSTRND2(I,KSUB) = 0
 70   CONTINUE
      DO 75 J1=1,4
      DO 75 K1=1,4
      IF(KNOWANS(J1,K1).EQ.2)KNOWANS(K1,J1)=2
   75 CONTINUE
      DO 80 I=1,2
      DO 80 M=1,4
      DO 80 KL=1,4
      NEANS2(I,M,KL) = NEANS1(I,M,KL)
 80   CONTINUE
      DO 90 M=1,2
      DO 90 JTN=1,4
      DO 90 L=1,4
      NEANS1(M,JTN,L) = 0
```

```
 90    CONTINUE
       IF (KPTR.EQ.1) 100,110
 100   RETURN
C        ZERO OUT DATASNT
 110   DO 120 JT=1,4
       DO 120 KSUB=1,4
       DATASNT(JT,KSUB) = 0.0
 120   CONTINUE
       DO 125 LM=1,4
       KWAIT2(LM)=0
  125 CONTINUE
       DO 126 LK=1,4
       DO 126 KM=1,2
       KWAIT1(LK,KM)=0
  126 CONTINUE
C           ZERO OUT ANVEC
       DO 130 I=1,5
       DO 130 JT=1,4
       ANVEC(I,JT) = 0.0
 130   CONTINUE
       DO 140 K=1,4
       ANVEC(K,K) = 1.
 140   CONTINUE
C           ZERO OUT INMATSNT
       DO 150 I=1,6
       DO 150 JT=1,4
       DO 150 K=1,5
       INMATSN(I,JT,K) = 0
 150   CONTINUE
       DO 155 J1=1,4
       DO 155 K1=1,4
       IF(KNOWANS(J1,K1).EQ.2)KNOWANS(J1,K1)=0
  155 CONTINUE
       DO 160 I=1,5
       DO 160 JT=1,4
       DO 160 K=1,5
       INMATRC(I,JT,K) = 0
 160   CONTINUE
C           ZERO MEANS
       DO 170 II=1,2
       DO 170 JT=1,4
       DO 170 K=1,4
       MEANS2(II,JT,K) = 0
 170   CONTINUE
       DO 175 J=1,4
       DO 175 K=1,2
       DATRTRN(K,J,2)=DATRTRN(K,J,1)
  175 CONTINUE
       DO 180 JT=1,4
       DO 180 KSUB=1,4
       LSTRND1(JT,KSUB) = 0
 180   CONTINUE
C           MOVE CUMSNT AND RCD INTO CUMATRCD AND SNT FOR   CUMULATIVE TO
       DO 190 I=1,6
       DO 190 JT=1,4
       DO 190 K=1,5
       CUMATSN(I,JT,K) = CUMSNT(I,JT,K)
 190   CONTINUE
       DO 200 I=1,5
```

```
      DO 200 JT=1,4
      DO 200 K=1,5
      CUMATRC(I,JT,K) = CUMRCO(I,JT,K)
 200  CONTINUE
C           ZERO CUMSNT AND CUMRCO
      DO 210 I=1,6
      DO 210 JT=1,4
      DO 210 K=1,5
      CUMSNT(I,JT,K) = 0.0
 210  CONTINUE
      DO 220 I=1,5
      DO 220 JT=1,4
      DO 220 K=1,5
      CUMRCO(I,JT,K) = 0.0
 220  CONTINUE
C           MOVE TMCLKS OVER
      IF (TMCLK(1).EQ.1.0) 230,240
 230  TMCLK(3) = TMCLK(2)
      GO TO 250
 240  TMCLK(5) = TMCLK(4)
      TMCLK(4) = TMCLK(3)
      TMCLK(3) = TMCLK(2)
 250  TMCLK(2) = 0.0
      RETURN
      END
```

```
      SUBROUTINE PRINT (IFLAG1,IFLAG2,IFLAG3,IFLAG4,IFLAG5,IFLAG6,IFLAG7
     $,IFLAG8,IFLAG9,IFLAG10)
      INCLUDE COMMON
      COMMON TMCLK(5),ANVEC(5,4),LSTRNO1(4,4),LQ(4),MEMMAT(4,4),MEVEC(4,
     $4),INMATSN(6,4,5),FLQ(2,2),LSTRNO2(4,4),INMATRC(5,4,5),CUMANS(4),
     $ANSHLD(5,4),LEQ(4),ITEST(2,3),DATASNT(4,4),OSNOVEC(4),OUT,CUMSNT(6
     $,4,5),CUMRCD(5,4,5),IHLD(4),IPKMAN(4,3),ALPHA,CUMATSN(6,4,5),
     $CUMATRC(5,4,5),NEANS1(2,4,4),NEANS2(2,4,4),KTEST(11,4),
     $KNOWANS(4,4),DATRTRN(2,4,2),RECHLD(4,2),KWAIT1(4,2),KWAIT2(4)
      REAL MEMMAT
      REAL MEVEC
      REAL INMATSN
      REAL INMATRC
      INTEGER OUT
      DIMENSION IFLAG(10)
      IF (IFLAG1.NE.1) GO TO 10
      WRITE (33,110)
      WRITE (33,120) ((MEMMAT(IL,JL),JL=1,4),IL=1,4)
 10   IF (IFLAG2.NE.1) GO TO 20
      WRITE (33,130)
      WRITE (33,140) ((MEVEC(IL,JL),JL=1,4),IL=1,4)
 20   IF (IFLAG3.NE.1) GO TO 30
      WRITE (OUT,150)
      WRITE (OUT,160) (((INMATSN(IL,JL,KL),KL=1,5),JL=1,4),IL=1,6)
 30   IF (IFLAG4.NE.1) GO TO 40
      WRITE (OUT,170)
      WRITE (OUT,180) (((INMATRC(IL,JL,KL),KL=1,5),JL=1,4),IL=1,5)
 40   IF (IFLAG5.NE.1) GO TO 50
      WRITE (OUT,190)
      WRITE (OUT,200) ((ANVEC(IL,JL),JL=1,4),IL=1,5)
 50   IF (IFLAG6.NE.1) GO TO 60
      WRITE (33,210) (TMCLK(LL),LL=1,2)
      WRITE (9,210)  (TMCLK(LL),LL=1,2)
 60   IF (IFLAG7.NE.1) GO TO 70
      WRITE (OUT,220)
      WRITE (OUT,230) (((NEANS2(IL,JL,KL),KL=1,4),JL=1,4),IL=1,2)
 70   IF (IFLAG8.NE.1) GO TO 80
      WRITE (OUT,240)
      WRITE (OUT,250) ((DATASNT(IL,JL),JL=1,4),IL=1,4)
 80   IF (IFLAG9.NE.1) GO TO 90
      WRITE (OUT,260)
      WRITE (OUT,270) ((LSTRNO2(IL,JL),JL=1,4),IL=1,4)
 90   IF (IFLAG10.NE.1) GO TO 100
      WRITE (OUT,280)
      WRITE (OUT,290) ((ANSHLD(IL,JL),JL=1,4),IL=1,5)
 100  RETURN
C
 110  FORMAT (≠ MEMMAT≠)
 120  FORMAT (4F7.4)
 130  FORMAT (≠ MEVEC≠)
 140  FORMAT (4F7.4)
 150  FORMAT (≠ INMATSN≠)
 160  FORMAT (4(2X,5F3.0))
 170  FORMAT (≠ INMATRC≠)
 180  FORMAT (4(2X,5F3.0))
 190  FORMAT (≠ ANVEC≠)
 200  FORMAT (4F3.0)
 210  FORMAT (F6.0,10X,F3.0)
 220  FORMAT (≠ NEANS2≠)
```

```
230   FORMAT (4(I9,4I3))
240   FORMAT (* DATASNT*)
250   FORMAT (4F5.0)
260   FORMAT (* LSTRND2*)
270   FORMAT (4I2)
280   FORMAT (* SNSHLD*)
290   FORMAT (4F3.0)
      END
```

```
      FUNCTION RNOG (ICODE)
C     NEW GENERATOR  FOR CDC 3200  1/19/73
C     GENERATES RANDOM NO., INTEGER LENGTH OF ICODE
C     ICODE=1      SET SEED
C     ICODE=2 THRU5      RETURN INTERGER, LENGTH OF ICODE
      IF (ICODE.GT.1) GO TO 10
      SEED = 543211234567890
   10 Y = RANDOM(SEED)
      IGEO = Y*(10**ICODE)
      RNOG = IGEO
      END
```

APPENDIX B

RAW AND TRANSFORMED DATA PLOTS

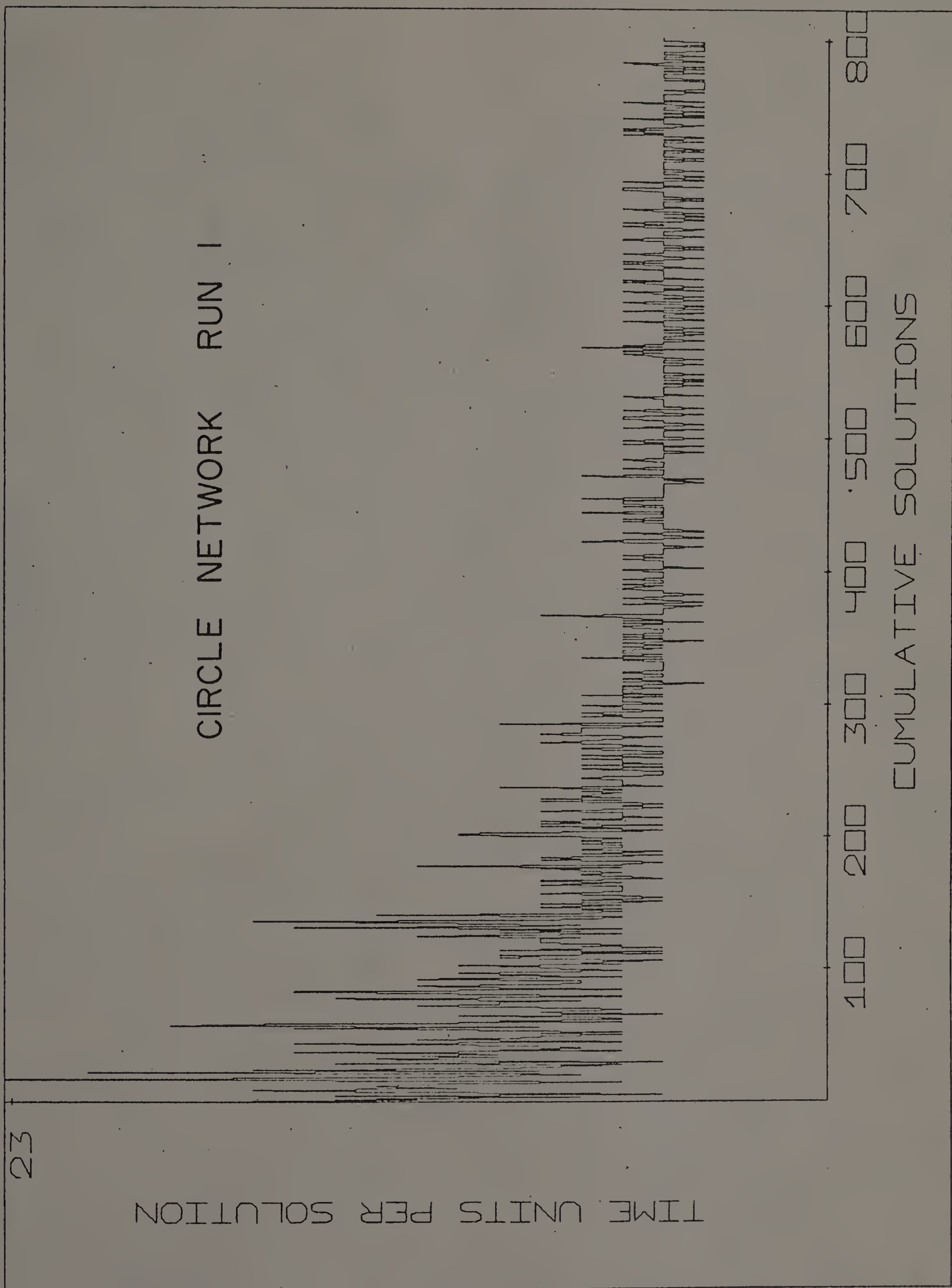
This appendix contains the computer plots of both the raw and logarithmic transformation data from the experiments performed on the simulation model. The order and notation is as follows:

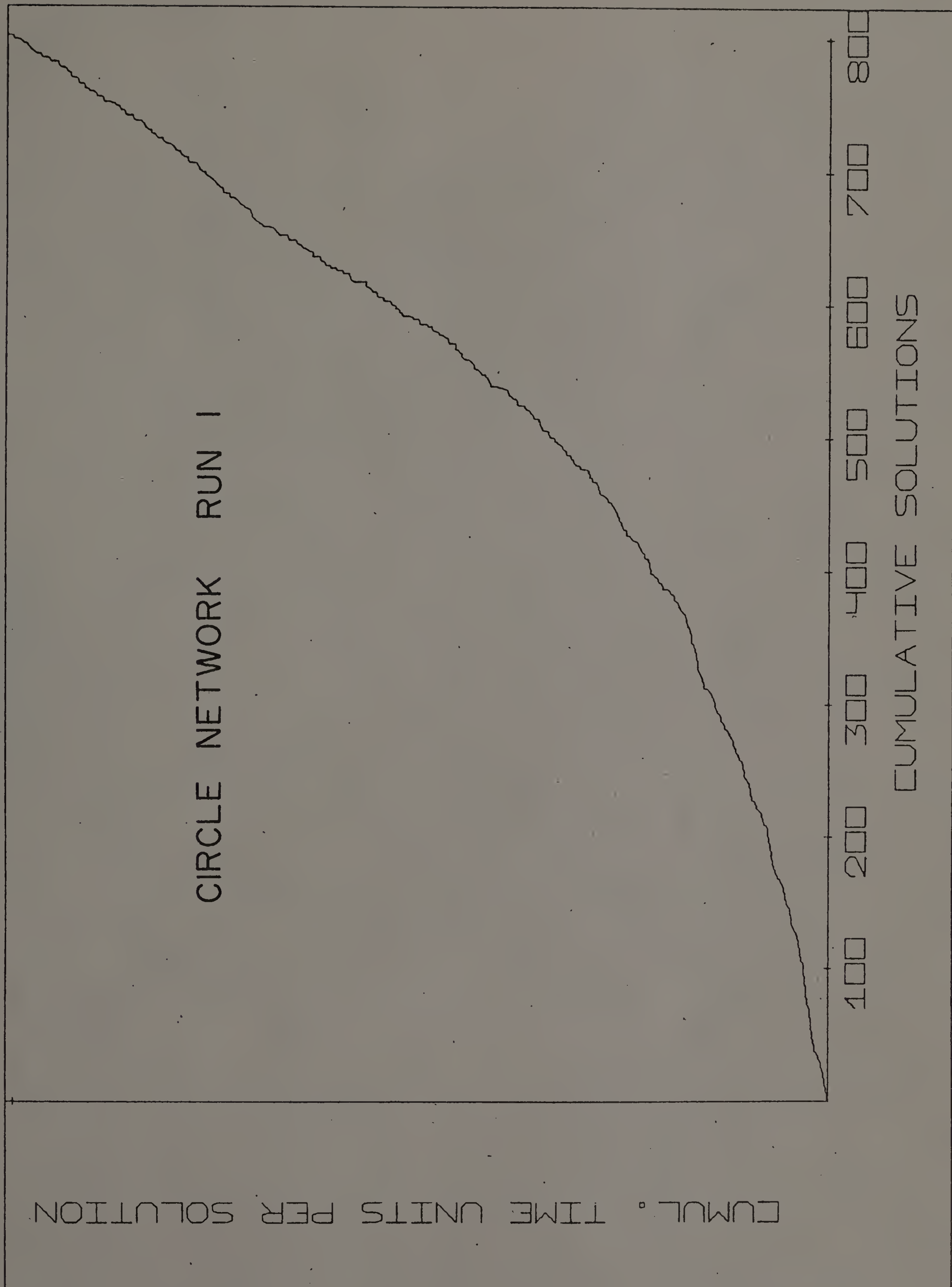
I. Circle Network

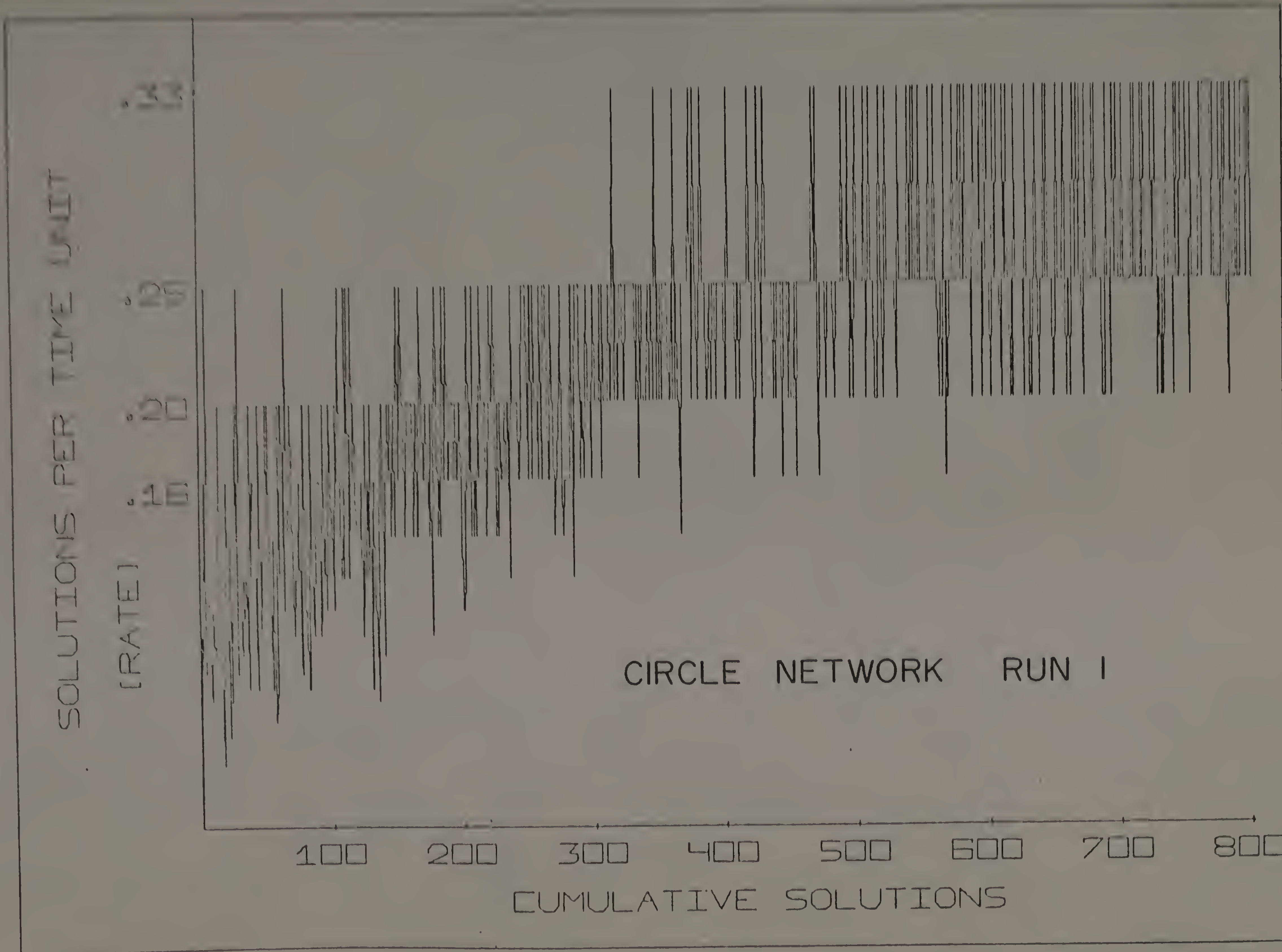
II. All-Channel Network

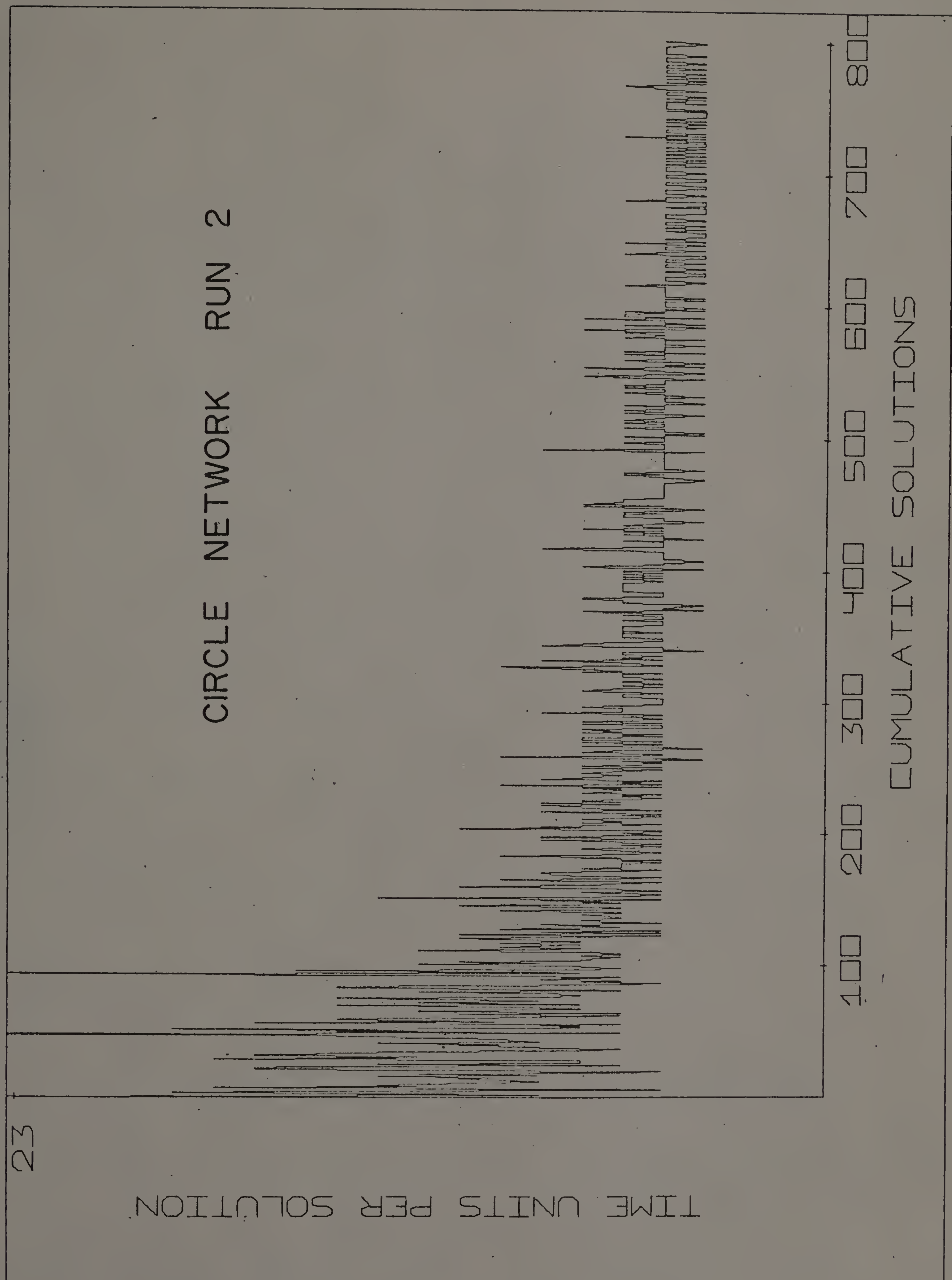
A set of three graphs for each of three experiments

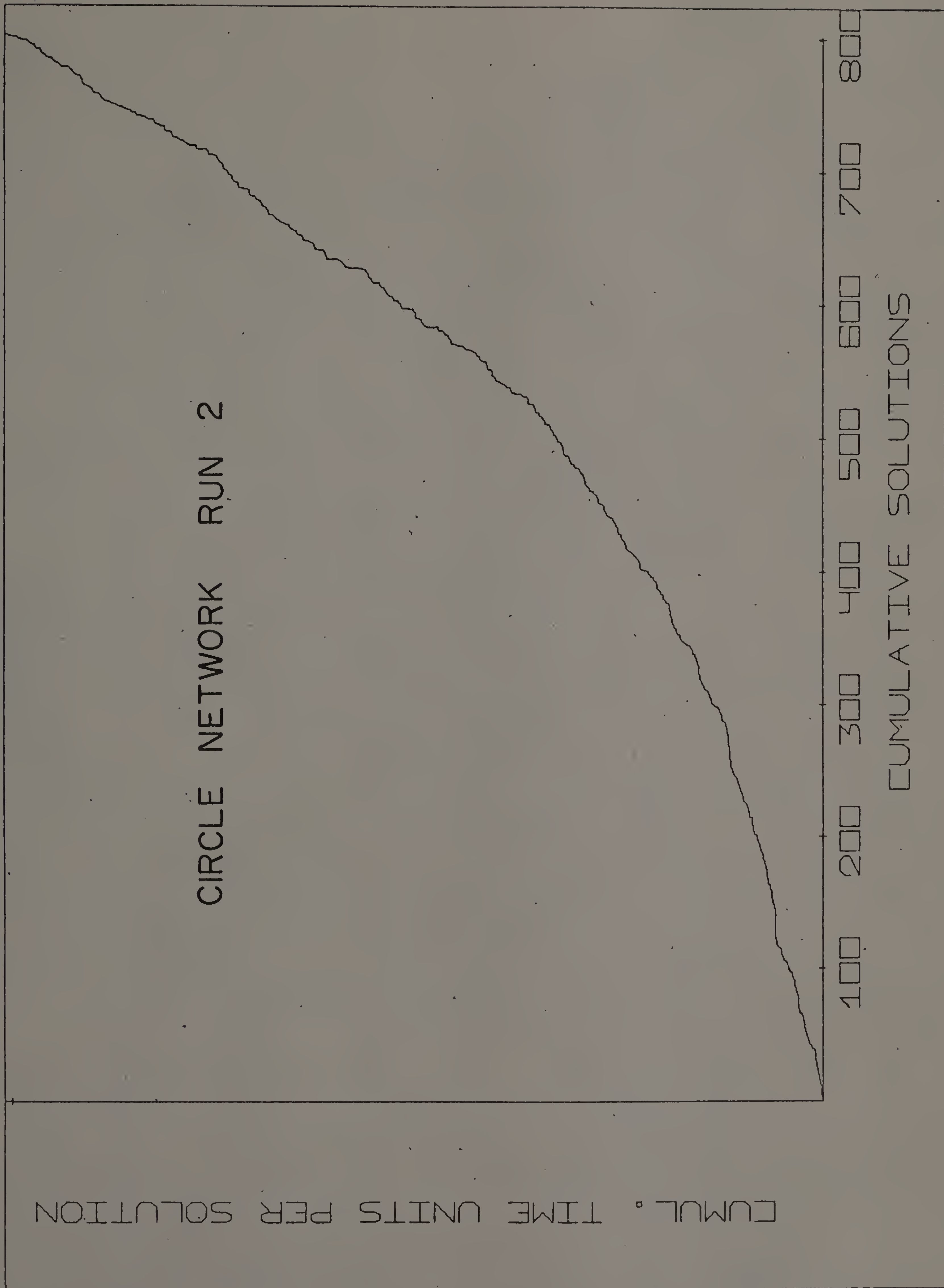
Experiment	Graphs
1. original run 1	1. raw data for time units per solution
2. replicated run 2	2. raw data for cumulative time units per solution
3. replicated run 3	3. transformed data for rate of solution over time.

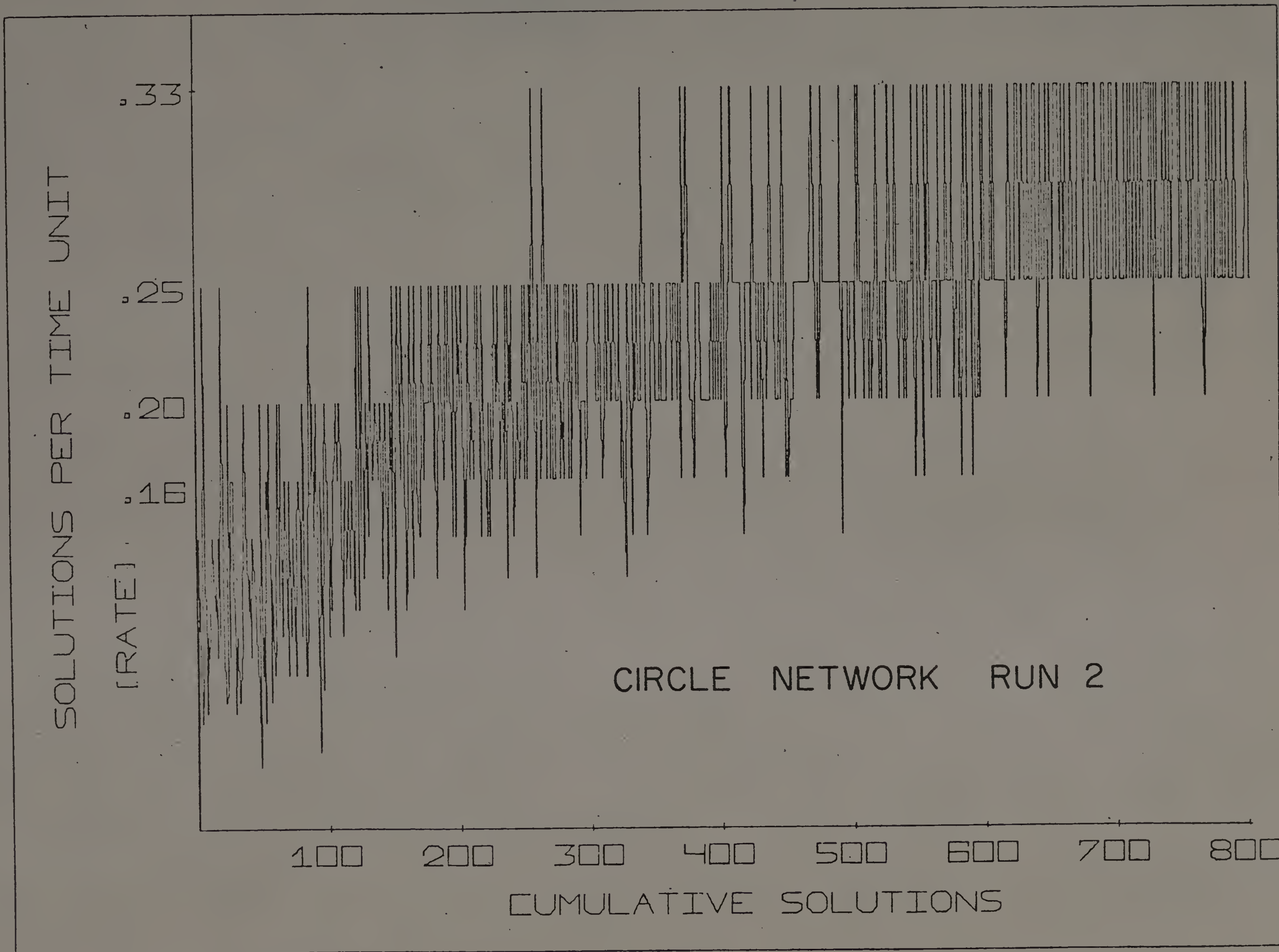

CIRCLE NETWORK RUN I
CUMULATIVE SOLUTIONS
TIME UNITS PER SOLUTION
23
100
200
300
400
500
600
700
800

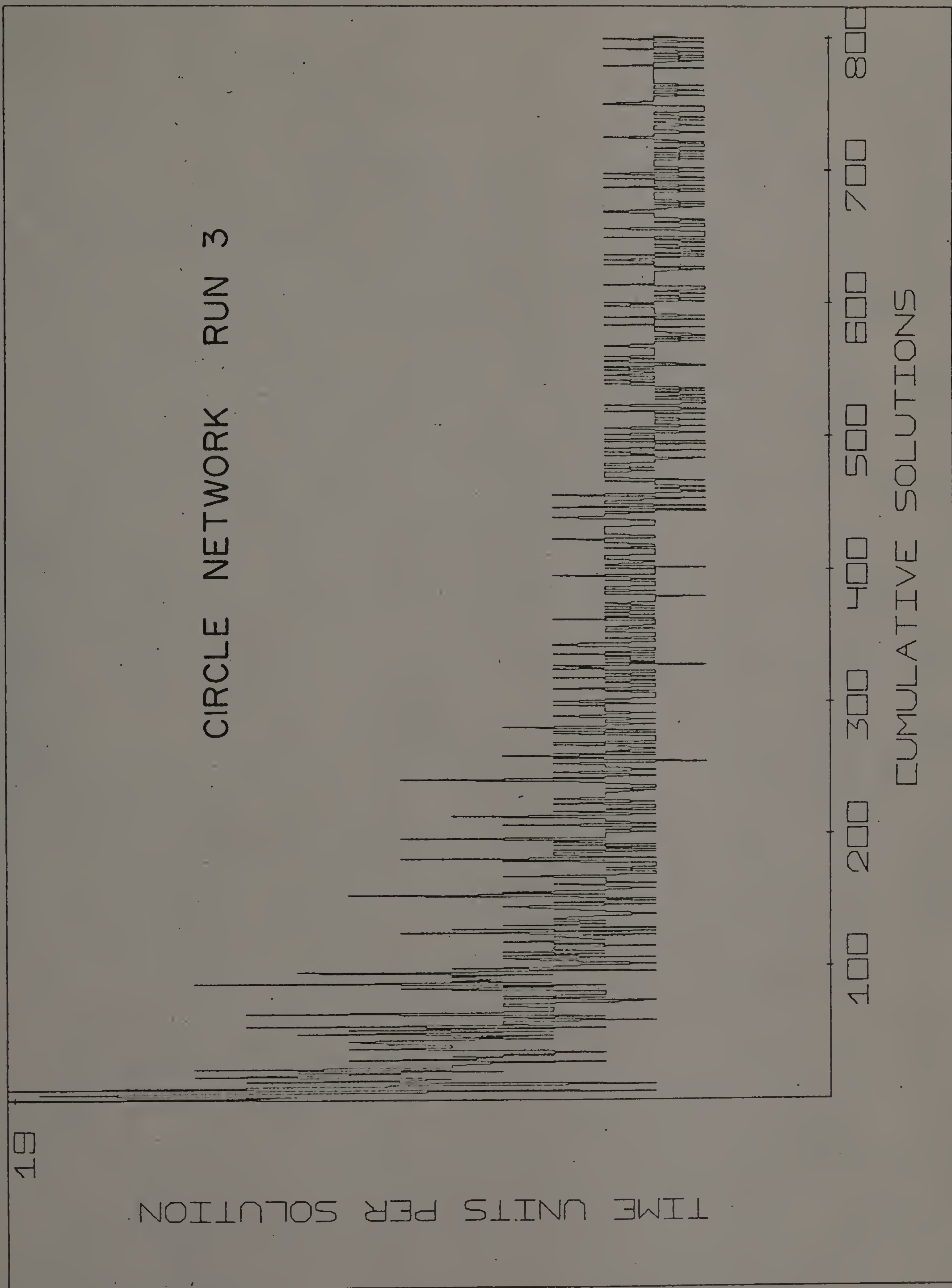

CIRCLE NETWORK RUN I
CUMULATIVE SOLUTIONS
100
200
300
400
500
600
700
800
CUMUL. TIME UNITS PER SOLUTION

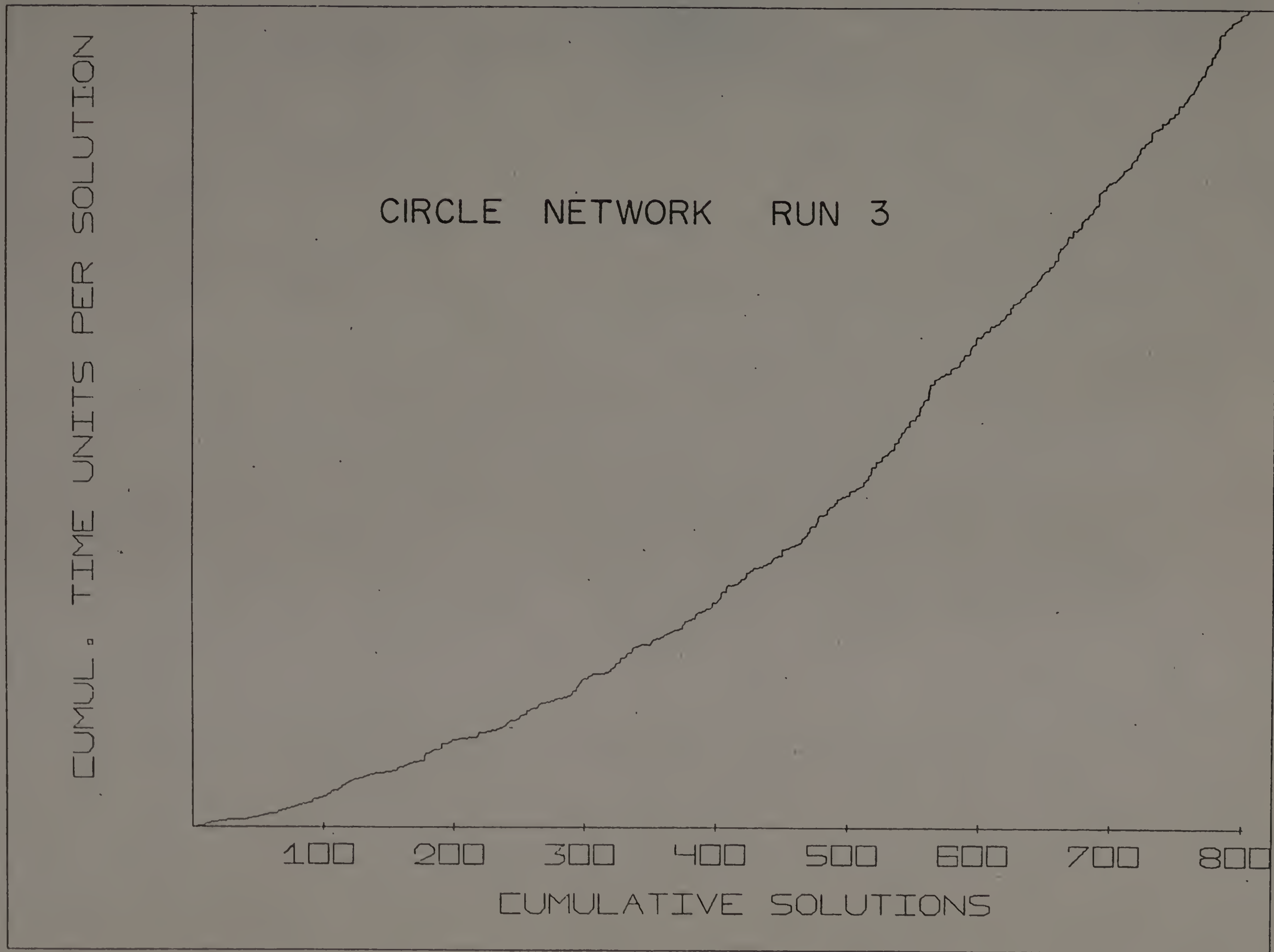

SOLUTIONS PER TIME UNIT
(RATE)
.33
.25
.20
.15
CIRCLE NETWORK RUN I
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS

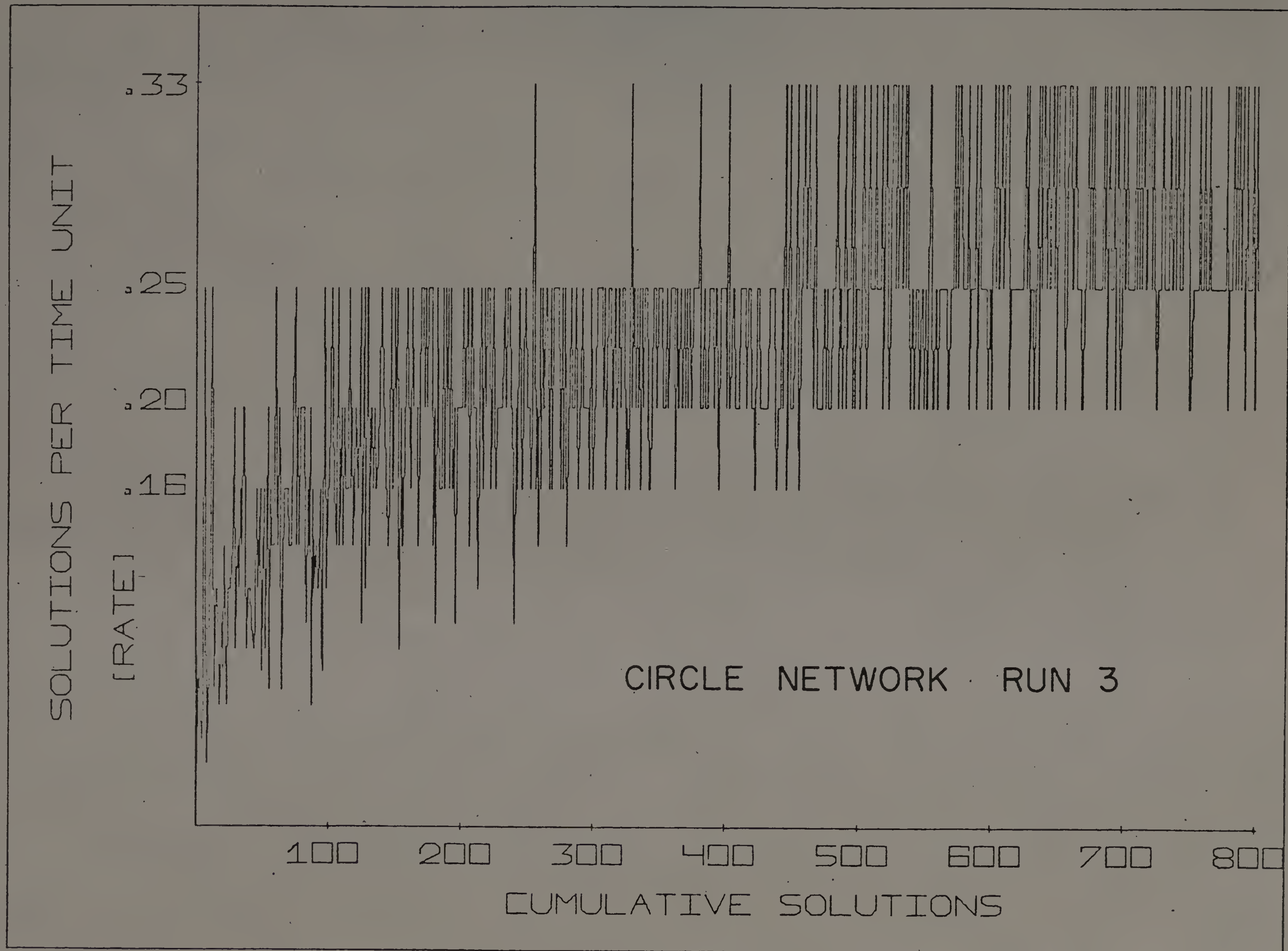

CIRCLE NETWORK RUN 2
CUMULATIVE SOLUTIONS
100
200
300
400
500
600
700
800
TIME UNITS PER SOLUTION
23

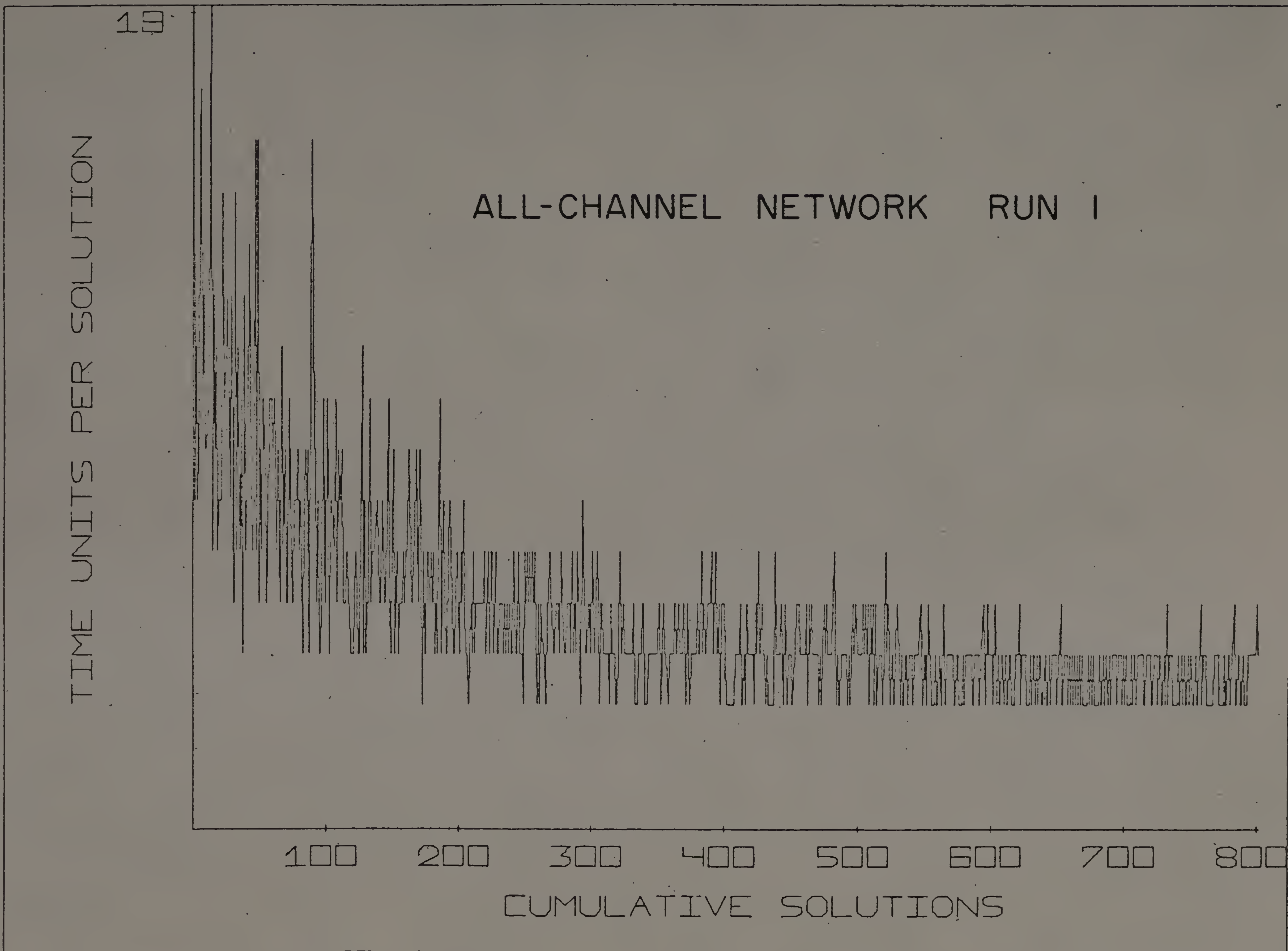

CIRCLE NETWORK RUN 2
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS
CUMUL. TIME UNITS PER SOLUTION

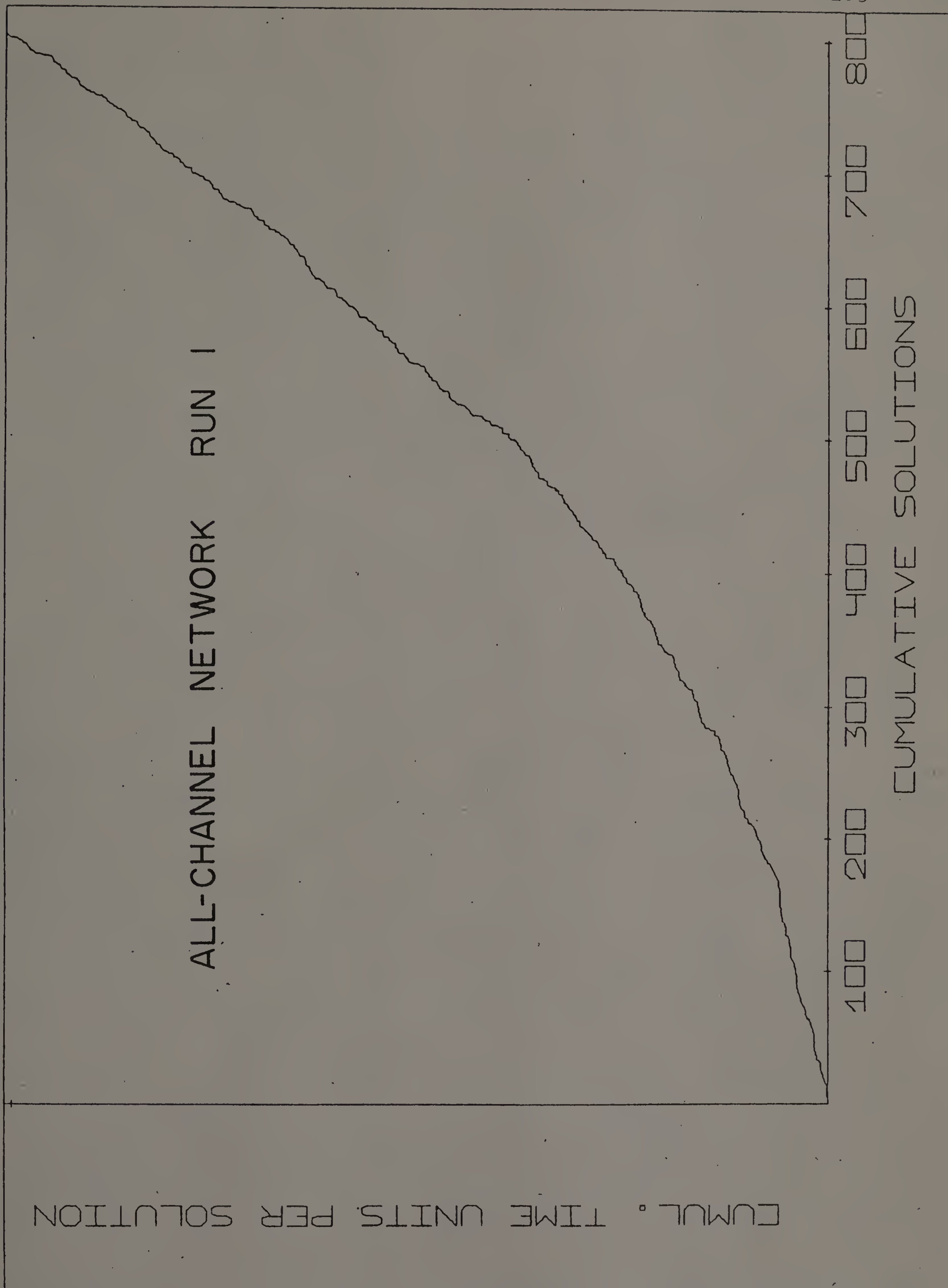

.33
.25
.20
.16
SOLUTIONS PER TIME UNIT
[RATE]
CIRCLE NETWORK RUN 2
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS

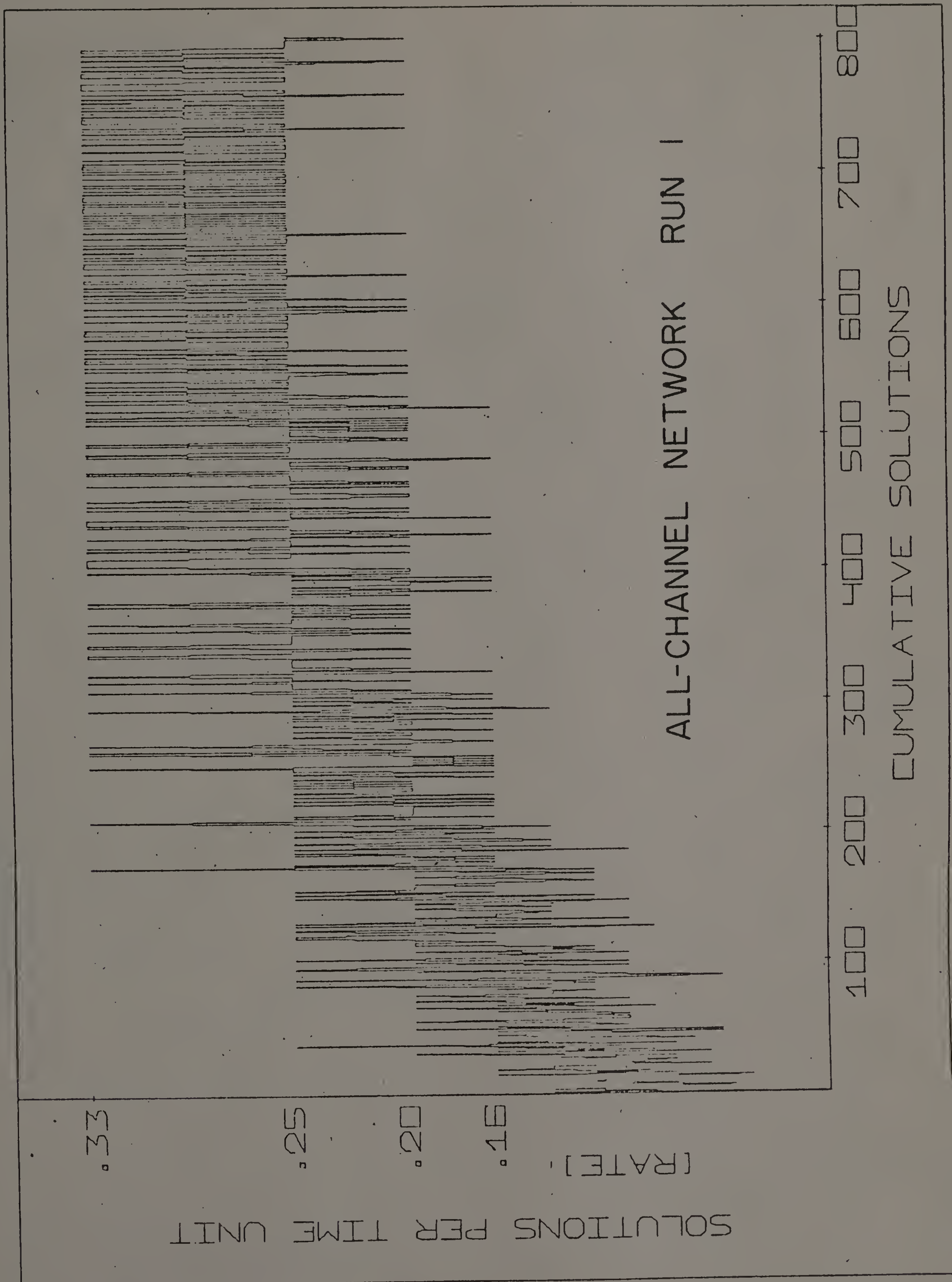

CIRCLE NETWORK RUN 3
TIME UNITS PER SOLUTION
19
CUMULATIVE SOLUTIONS
100
200
300
400
500
600
700
800

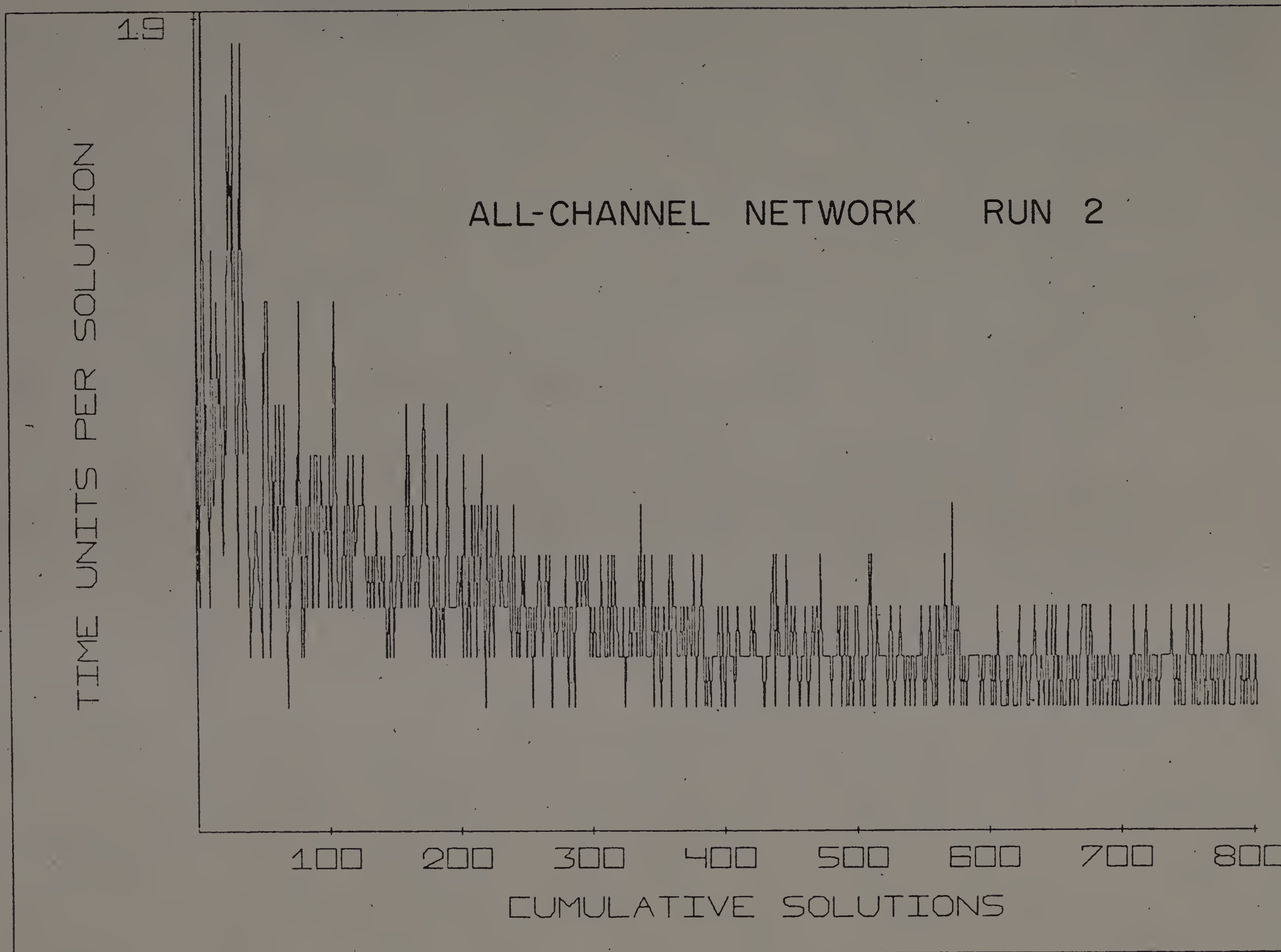

CIRCLE NETWORK RUN 3
CUMUL. TIME UNITS PER SOLUTION
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS

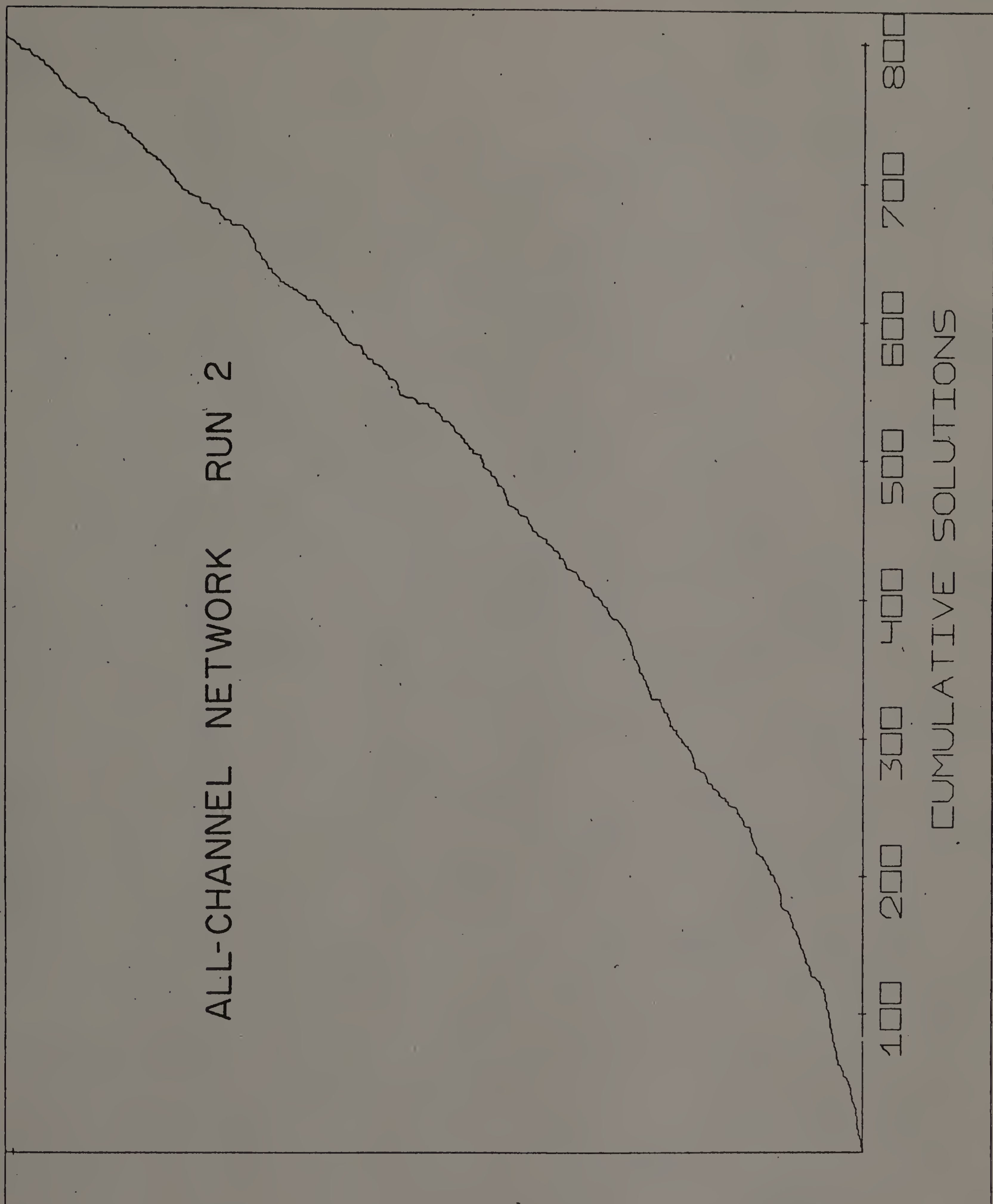

CIRCLE NETWORK RUN 3
SOLUTIONS PER TIME UNIT
[RATE]
.33
.25
.20
.16
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS

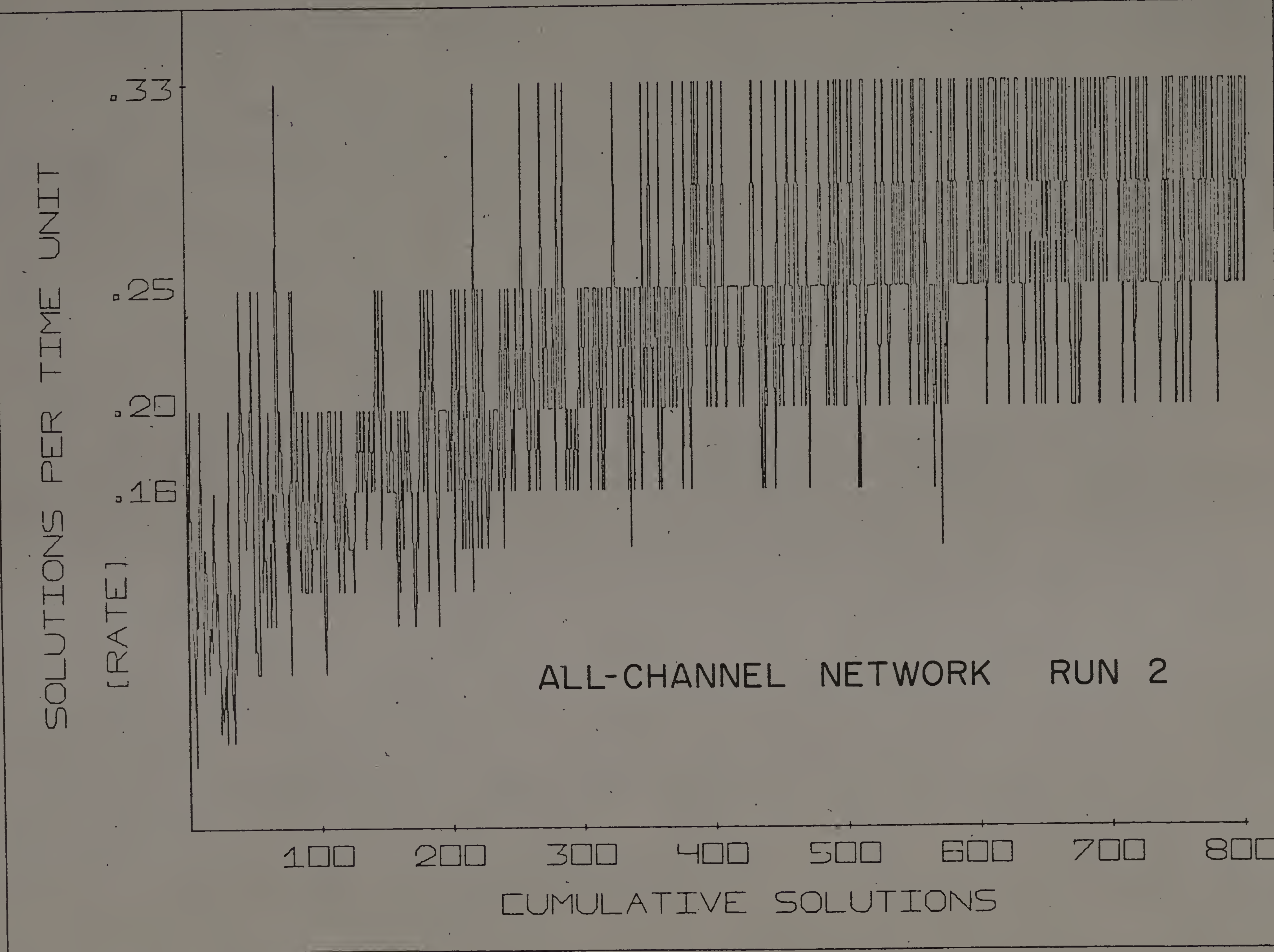

ALL-CHANNEL NETWORK RUN I
TIME UNITS PER SOLUTION
19
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS


ALL-CHANNEL NETWORK RUN I
CUMULATIVE SOLUTIONS
100
200
300
400
500
600
700
800
CUMUL. TIME UNITS PER SOLUTION

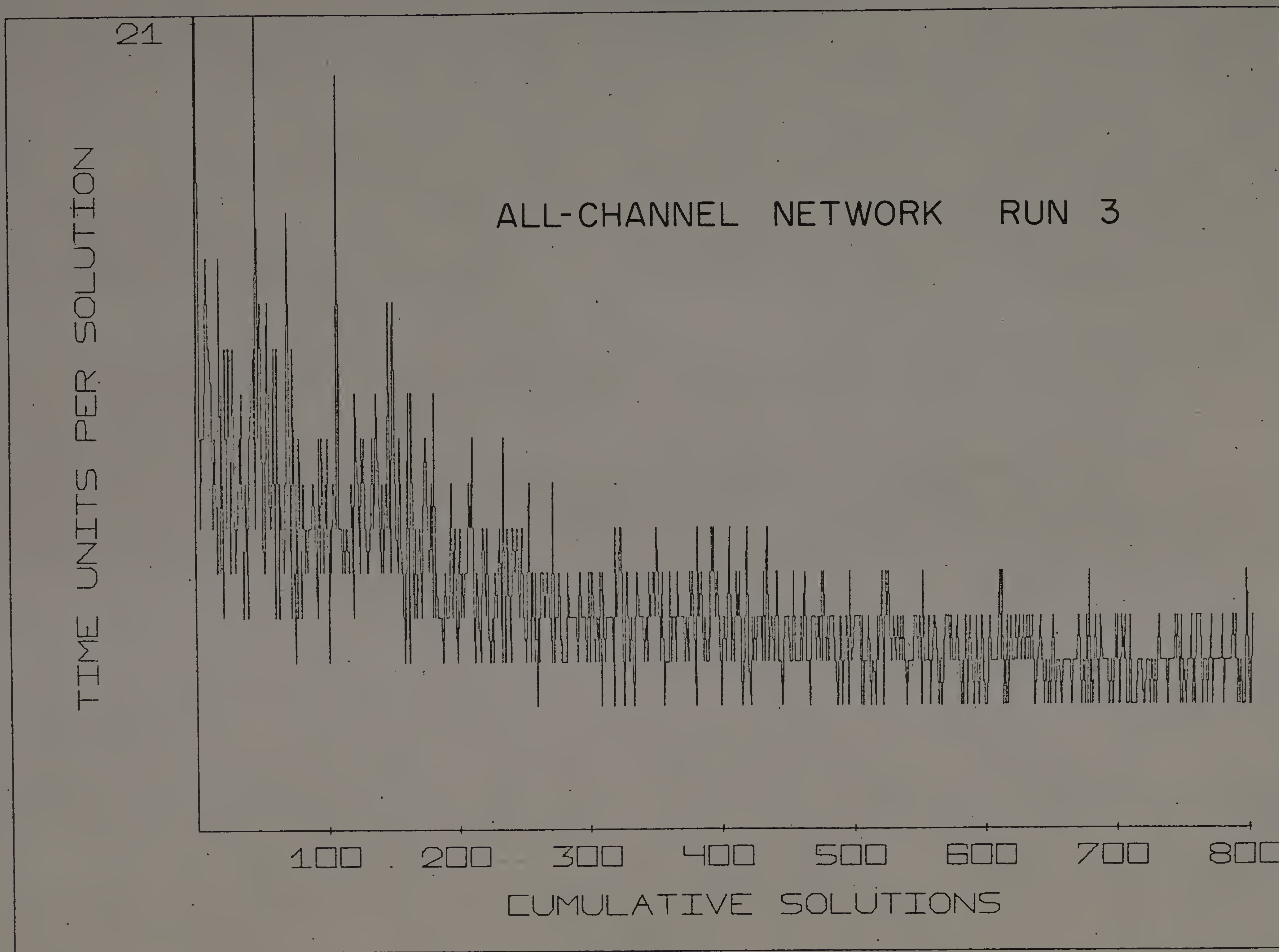

ALL-CHANNEL NETWORK RUN I
CUMULATIVE SOLUTIONS
100
200
300
400
500
600
700
800
SOLUTIONS PER TIME UNIT
[RATE]
.33
.25
.20
.16

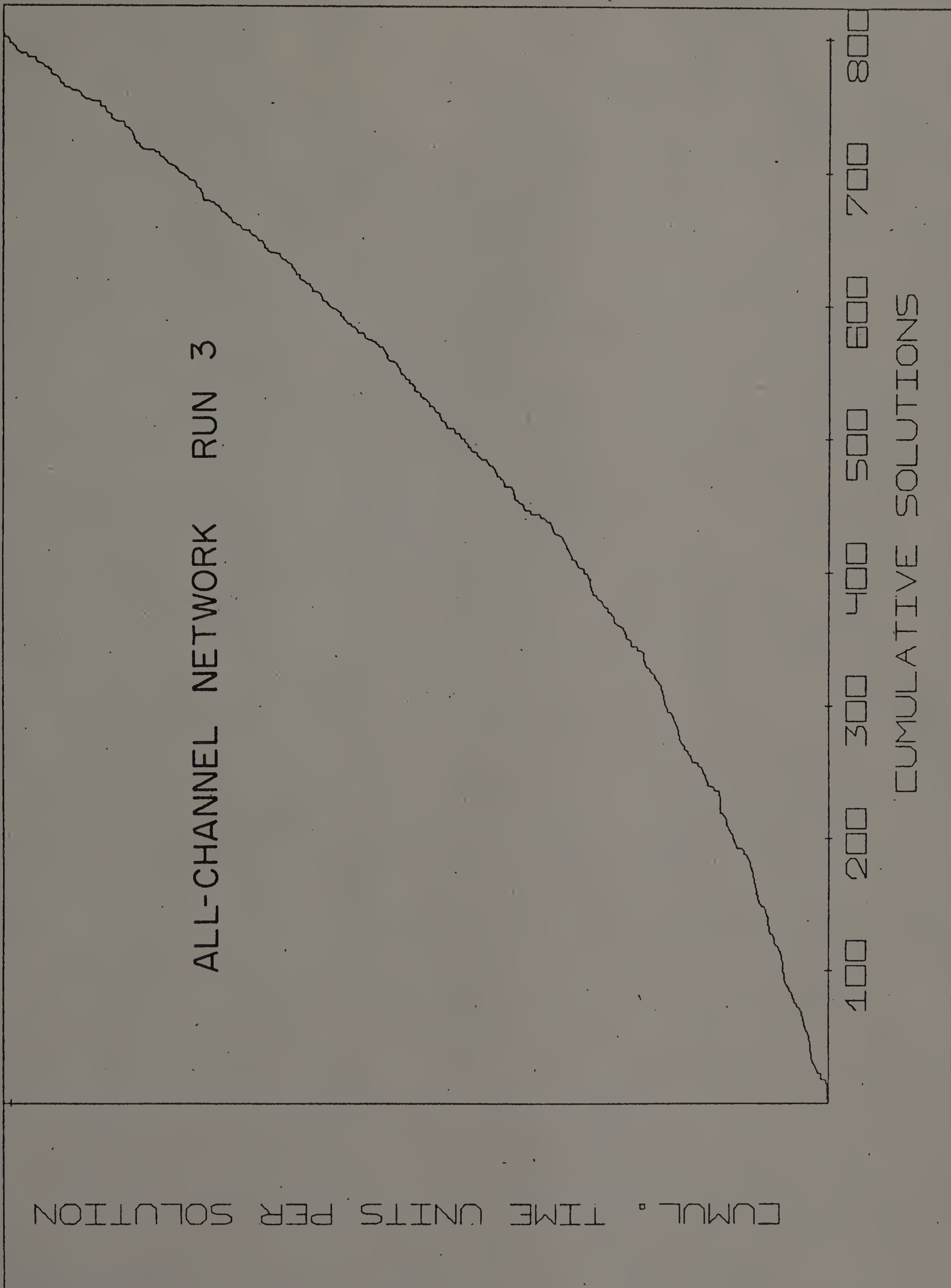

ALL-CHANNEL NETWORK RUN 2
TIME UNITS PER SOLUTION
19
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS

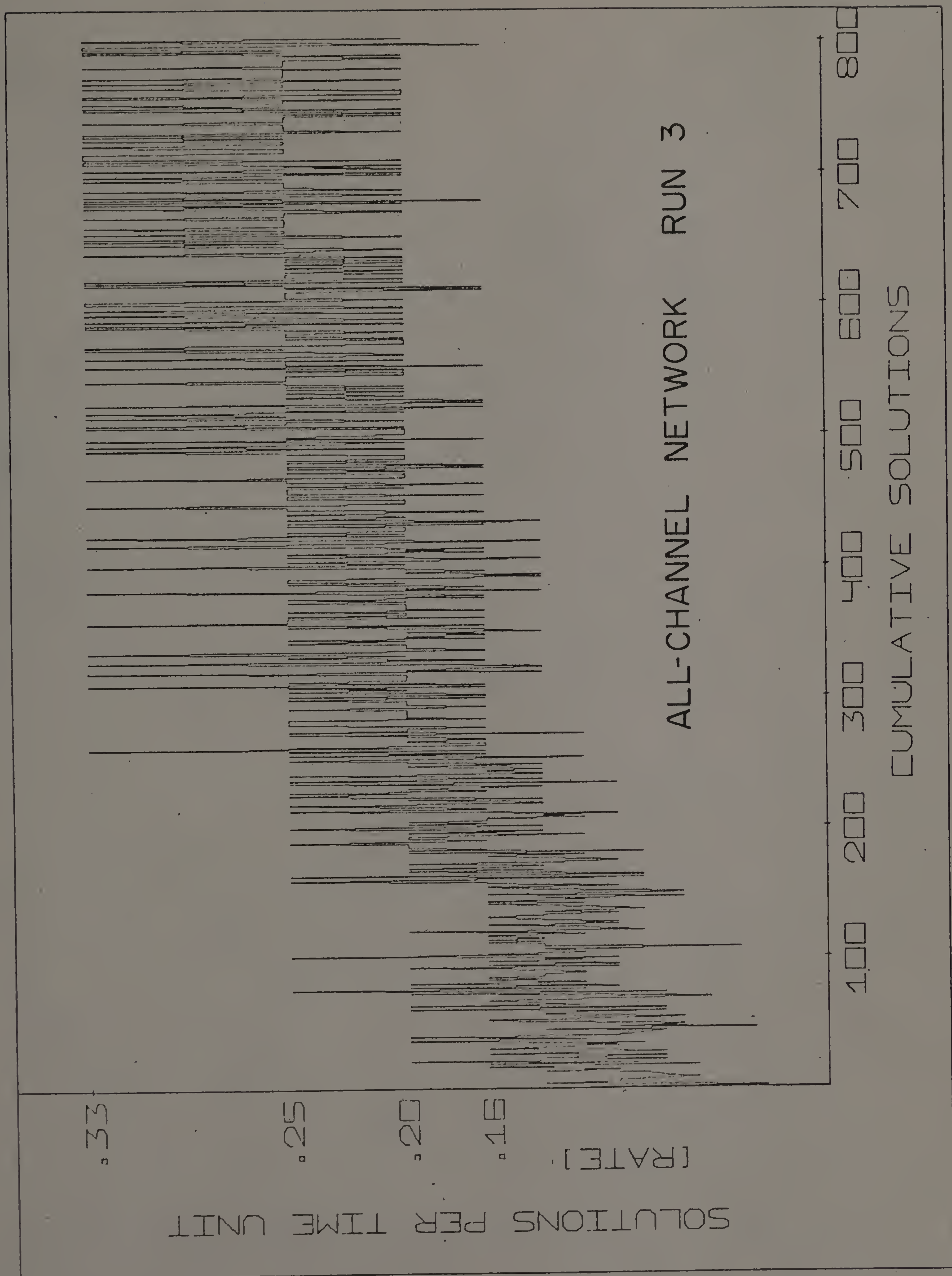

ALL-CHANNEL NETWORK RUN 2
100 200 300 400 500 600 700 800
CUMULATIVE SOLUTIONS
CUMUL. TIME UNITS PER SOLUTION



ALL-CHANNEL NETWORK RUN 2
SOLUTIONS PER TIME UNIT
[RATE]
.33
.25
.20
.16
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS


ALL-CHANNEL NETWORK RUN 3
21
TIME UNITS PER SOLUTION
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS


ALL-CHANNEL NETWORK RUN 3
CUMULATIVE SOLUTIONS
100
200
300
400
500
600
700
800
CUMUL. TIME UNITS PER SOLUTION


ALL-CHANNEL NETWORK RUN 3
CUMULATIVE SOLUTIONS
100
200
300
400
500
600
700
800
SOLUTIONS PER TIME UNIT
[RATE]
.33
.25
.20
.15

APPENDIX C

RAW DATA FOR SIMULATED EXPERIMENT

This appendix contains the raw data for Circle Network replication run five. The right column records the number of rounds for successive trials. After every twenty trials the probability states of channel selection (MEMMAT) and message choice (MEVEC) are recorded throughout 800 trials.

```
          1          19
          2          14
          3          22
          4          10
          5          17
          6          13
          7           4
          8           6
          9          15
         10          10
         11          11
         12          10
         13           7
         14           8
         15           9
         16           8
         17          11
         18           7
         19          10
         20           5
    MEMMAT
          0   .4725       0   .9999
      .4918       0   .9999       0
          0   .5096       0   .9999
      .5276       0   .9999       0
    MEVEC
      .1745   .0833   .1014   .1195
      .4620   .3703   .3515   .4435
      .7121   .6743   .6759   .7133
      .9999   .9999   .9999   .9999
         21           4
         22          10
         23          14
         24          14
         25          13
         26           5
         27          11
         28           6
         29           6
         30          15
         31          11
         32          10
         33          14
         34          14
         35          11
         36          11
         37           6
         38           5
         39           7
```

40 7

MEMMAT

0	.4623	0	.9999
.5127	0	.9999	0
0	.5083	0	.9999
.5223	0	.9999	0

MEVEC

.2164	.0851	.1538	.0976
.4713	.3196	.3777	.4529
.6953	.6212	.6733	.7076
.9999	.9993	.9999	.9999

41	9
42	8
43	11
44	7
45	8
46	9
47	12
48	12
49	23
50	5
51	12
52	10
53	16
54	6
55	6
56	7
57	5
58	14
59	8
60	12

MEMMAT

0	.4407	0	.9999
.4832	0	.9999	0
0	.5182	0	.9999
.5480	0	.9999	0

MEVEC

.2444	.0938	.1712	.0848
.4841	.3170	.4014	.4504
.6966	.6165	.6623	.6893
.9999	.9999	.9999	.9999

61	10
62	6
63	5
64	9
65	5
66	10
67	10
68	6
69	6

```
   70            8
   71           12
   72            6
   73           10
   74           10
   75            7
   76           12
   77            7
   78            6
   79            6
   80            7
MEMMAT
     0   .4764       0   .9999
 .4752       0   .9999       0
     0   .4885       0   .9999
 .5153       0   .9999       0
MEVEC
 .2954   .1325   .2132   .1051
 .5137   .3559   .4421   .4653
 .6909   .6056   .6796   .7029
 .9999   .9999   .9999   .9999
   81           10
   82            5
   83            6
   84           12
   85           12
   86            9
   87            5
   88            4
   89            6
   90            5
   91            7
   92            5
   93            8
   94           20
   95            6
   96            7
   97           13
   98            6
   99            5
  100            6
MEMMAT
     0   .4537       0   .9999
 .4524       0   .9999       0
     0   .5192       0   .9999
 .4873       0   .9999       0
MEVEC
 .3010   .1456   .2727   .1272
 .5218   .3692   .4805   .4630
 .6887   .6346   .6786   .6611
 .9999   .9999   .9999   .9999
```

101	6
102	10
103	7
104	9
105	6
106	6
107	5
108	6
109	5
110	5
111	5
112	10
113	7
114	6
115	8
116	7
117	6
118	8
119	6
120	6

MEMMAT

0	.4345	0	.9999
.4525	0	.9999	0
0	.5407	0	.9999
.5175	0	.9999	0

MEVEC

.3614	.1779	.3566	.1260
.5629	.3817	.5469	.4252
.7405	.6030	.7120	.6266
.9999	.9993	.9999	.9999

121	8
122	9
123	4
124	9
125	4
126	7
127	4
128	8
129	7
130	5
131	6
132	7
133	4
134	5
135	6
136	6
137	5
138	5
139	6
140	5

MEMMAT

0	.4333	0	.9999
.4482	0	.9999	0
0	.5452	0	.9999
.5254	0	.9999	0

MEVEC

.4083	.2471	.4042	.1655
.5832	.4240	.6066	.4441
.7551	.6161	.7500	.6389
.9999	.9999	.9999	.9999

141	5
142	8
143	6
144	5
145	5
146	9
147	7
148	5
149	5
150	7
151	4
152	11
153	6
154	4
155	5
156	6
157	4
158	5
159	5
160	9

MEMMAT

0	.4543	0	.9999
.4853	0	.9999	0
0	.5457	0	.9999
.5319	0	.9999	0

MEVEC

.4897	.2819	.4082	.2131
.6355	.4293	.6132	.4634
.7958	.6419	.7327	.6258
.9999	.9999	.9999	.9999

161	8
162	6
163	5
164	4
165	6
166	8
167	5
168	4
169	6
170	7

171	7
172	5
173	4
174	6
175	5
176	5
177	5
178	5
179	4
180	5

MEMMAT

0	.4647	0	.9999
.5074	0	.9999	0
0	.5401	0	.9999
.5258	0	.9999	0

MEVEC

.5464	.3621	.4452	.2103
.6655	.4825	.6126	.4696
.7965	.6737	.7276	.6403
.9999	.9999	.9999	.9999

181	4
182	6
183	5
184	9
185	6
186	4
187	5
188	5
189	6
190	5
191	4
192	5
193	4
194	5
195	5
196	7
197	4
198	7
199	7
200	4

MEMMAT

0	.4530	0	.9999
.5051	0	.9999	0
0	.5337	0	.9999
.5216	0	.9999	0

MEVEC

.5745	.4215	.4375	.1999
.6758	.5240	.5800	.4727
.7873	.6866	.6967	.6375
.9999	.9999	.9999	.9999

201	5
202	4
203	4
204	9
205	6
206	7
207	5
208	4
209	6
210	5
211	5
212	6
213	5
214	4
215	5
216	4
217	7
218	4
219	5
220	6

MEMMAT

0	.4829	0	.9999
.5221	0	.9999	0
0	.5043	0	.9999
.4994	0	.9999	0

MEVEC

.6523	.4911	.4499	.2720
.7351	.5749	.6202	.4956
.8262	.7269	.7155	.6661
.9999	.9993	.9999	.9999

221	6
222	7
223	5
224	7
225	5
226	6
227	5
228	4
229	5
230	5
231	4
232	6
233	5
234	5
235	5
236	4
237	8
238	4
239	5
240	5

MEMMAT

0	.5047	0	.9999
.5568	0	.9999	0
0	.4871	0	.9999
.4795	0	.9999	0

MEVEC

.7042	.5309	.5320	.2687
.7747	.6021	.6768	.4763
.8521	.7492	.7579	.6791
.9999	.9999	.9999	.9999

241	4
242	7
243	6
244	6
245	5
246	5
247	6
248	5
249	4
250	6
251	4
252	6
253	5
254	4
255	4
256	5
257	3
258	4
259	8
260	5

MEMMAT

0	.5304	0	.9999
.5540	0	.9999	0
0	.4597	0	.9999
.4718	0	.9999	0

MEVEC

.7334	.5353	.5743	.2953
.8121	.5947	.6951	.5076
.8767	.7733	.7627	.6766
.9999	.9999	.9999	.9999

261	4
262	4
263	6
264	5
265	3
266	4
267	6
268	4
269	4
270	6

```
   271            4
   272            6
   273            6
   274            6
   275            4
   276            5
   277            4
   278            6
   279            5
   280            6
 MEMMAT
      0   .4965       0   .9999
  .6085       0   .9999       0
      0   .4579       0   .9999
  .4321       0   .9999       0
 MEVEC
  .7777   .5769   .6093   .3759
  .8433   .6263   .7288   .5529
  .8972   .7941   .7851   .7112
  .9999   .9993   .9999   .9999
   281            4
   282            4
   283            4
   284            6
   285            4
   286            6
   287            5
   288            4
   289            4
   290            5
   291            4
   292            4
   293            7
   294            5
   295            5
   296            5
   297            6
   298            5
   299            4
   300            4
 MEMMAT
      0   .5332       0   .9999
  .6089       0   .9999       0
      0   .4461       0   .9999
  .4423       0   .9999       0
 MEVEC
  .7743   .5826   .6493   .4129
  .8302   .6248   .7515   .5635
  .8759   .8043   .7935   .7351
  .9999   .9999   .9999   .9999
```

```
 301          4
 302          4
 303          4
 304          4
 305          5
 306          5
 307          5
 308          4
 309          5
 310          6
 311          5
 312          4
 313          5
 314          4
 315          4
 316          5
 317          5
 318          4
 319          4
 320          5
MEMMAT
     0   .5392       0   .9999
 .6088       0   .9999       0
     0   .4612       0   .9939
 .4378       0   .9399       0
MEVEC
 .7960   .5833   .6451   .4501
 .8465   .5220   .7370   .5862
 .8879   .8043   .7803   .7413
 .9999   .9999   .9999   .9999
 321          5
 322          5
 323          4
 324          6
 325          5
 326          6
 327          8
 328          4
 329          4
 330          5
 331          5
 332          7
 333          4
 334          5
 335          5
 336          4
 337          5
 338          5
 339          5
 340          3
```

MEMMAT

0	.5454	0	.9999
.5880	0	.9999	0
0	.4365	0	.9999
.4342	0	.9999	0

MEVEC

.8156	.6054	.6415	.4649
.8612	.6393	.7246	.5879
.8986	.8047	.7638	.7281
.9999	.9999	.9999	.9999

341	4
342	4
343	7
344	6
345	6
346	5
347	4
348	4
349	4
350	5
351	5
352	5
353	5
354	4
355	5
356	5
357	5
358	5
359	4
360	4

MEMMAT

0	.5773	0	.9999
.5773	0	.9999	0
0	.4247	0	.9999
.4226	0	.9999	0

MEVEC

.8366	.6505	.6632	.4691
.8771	.6810	.7368	.5781
.9102	.8270	.7907	.7023
.9999	.9999	.9999	.9999

361	4
362	4
363	5
364	4
365	4
366	4
367	5
368	4
369	5
370	6

371	3
372	4
373	4
374	3
375	4
376	5
377	5
378	5
379	6
380	6

MEMMAT

0	.6101	0	.9999
.6102	0	.9999	0
0	.4305	0	.9999
.4094	0	.9999	0

MEVEC

.8493	.6776	.6894	.4719
.8866	.7058	.7572	.5920
.9172	.8404	.8070	.7066
.9999	.9999	.9999	.9999

381	4
382	4
383	4
384	4
385	5
386	5
387	5
388	5
389	5
390	5
391	5
392	4
393	4
394	5
395	4
396	5
397	4
398	5
399	4
400	5

MEMMAT

0	.6093	0	.9999
.6288	0	.9999	0
0	.3892	0	.9999
.4473	0	.9999	0

MEVEC

.8638	.5694	.6992	.5026
.8975	.6949	.7606	.6112
.9251	.8165	.8255	.7148
.9999	.9999	.9999	.9999

```
  401              5
  402              3
  403              5
  404              6
  405              4
  406              4
  407              3
  408              3
  409              4
  410              4
  411              4
  412              4
  413              4
  414              4
  415              4
  416              5
  417              7
  418              6
  419              4
  420              4
MEMMAT
     0   .6474       0   .9999
 .6644       0   .9999       0
     0   .3702       0   .9999
 .4043       0   .9999       0
MEVEC
 .8769   .6815   .7281   .5116
 .9073   .7045   .7335   .6098
 .9323   .8145   .8423   .7033
 .9999   .9993   .9999   .9999
  421              4
  422              4
  423              5
  424              3
  425              4
  426              4
  427              4
  428              5
  429              4
  430              5
  431              4
  432              6
  433              4
  434              4
  435              5
  436              4
  437              3
  438              4
  439              4
  440              4
```

```
MEMMAT
      0   .6683       0   .9999
  .6647       0   .9999       0
      0   .3280       0   .9999
  .4151       0   .9999       0
MEVEC
  .8909   .6991   .7395   .5674
  .9179   .7383   .7887   .6543
  .9400   .8357   .8603   .7372
  .9999   .9999   .9999   .9999
   441              5
   442              5
   443              5
   444              4
   445              5
   446              4
   447              3
   448              4
   449              6
   450              4
   451              6
   452              5
   453              5
   454              5
   455              4
   456              4
   457              4
   458              4
   459              4
   460              4
MEMMAT
      0   .6874       0   .9999
  .6645       0   .9999       0
      0   .3282       0   .9999
  .4265       0   .9999       0
MEVEC
  .9034   .7334   .7693   .5407
  .9273   .7681   .8128   .6365
  .9469   .8545   .8762   .7291
  .9999   .9999   .9999   .9999
   461              4
   462              4
   463              4
   464              4
   465              4
   466              4
   467              4
   468              3
   469              3
   470              4
```

471	4
472	5
473	4
474	5
475	4
476	3
477	4
478	4
479	4
480	4

MEMMAT

0	.7175	0	.9999
.6768	0	.9999	0
0	.3743	0	.9999
.4055	0	.9999	0

MEVEC

.9127	.7590	.7914	.5948
.9343	.7904	.8308	.6714
.9520	.8684	.8881	.7552
.9999	.9999	.9999	.9999

481	4
482	4
483	4
484	4
485	4
486	4
487	4
488	4
489	4
490	3
491	7
492	4
493	4
494	4
495	4
496	4
497	5
498	4
499	4
500	4

MEMMAT

0	.7141	0	.9999
.6958	0	.9999	0
0	.3715	0	.9999
.3816	0	.9999	0

MEVEC

.9178	.7732	.7841	.6092
.9381	.8027	.8211	.6908
.9548	.8762	.8751	.7696
.9999	.9999	.9999	.9999

501	5
502	3
503	4
504	3
505	4
506	4
507	4
508	5
509	4
510	4
511	4
512	5
513	4
514	5
515	4
516	4
517	3
518	4
519	5
520	4

MEMMAT

0	.7279	0	.9999
.7105	0	.9999	0
0	.3667	0	.9999
.3765	0	.9999	0

MEVEC

.9272	.7991	.8088	.6354
.9452	.9253	.8415	.7076
.9600	.8903	.8893	.7959
.9999	.9993	.9999	.9999

521	5
522	4
523	4
524	4
525	5
526	3
527	3
528	4
529	4
530	4
531	3
532	4
533	4
534	5
535	4
536	4
537	4
538	5
539	4
540	5

MEMMAT

0	.7409	0	.9999
.7051	0	.9993	0
0	.3618	0	.9999
.3715	0	.9999	0

MEVEC

.9174	.8220	.8306	.6190
.9334	.8452	.8596	.6829
.9464	.9028	.9020	.7611
.9999	.9993	.9999	.9999

541	4
542	4
543	4
544	4
545	3
546	6
547	5
548	4
549	3
550	4
551	4
552	5
553	6
554	3
555	4
556	4
557	3
558	4
559	5
560	4

MEMMAT

0	.7573	0	.9999
.7244	0	.9999	0
0	.3690	0	.9999
.3794	0	.9999	0

MEVEC

.9283	.8455	.8529	.6330
.9421	.8656	.8781	.7063
.9535	.9156	.9149	.7742
.9999	.9993	.9999	.9999

561	4
562	4
563	5
564	3
565	5
566	4
567	4
568	4
569	4
570	3

```
     571              4
     572              4
     573              4
     574              4
     575              3
     576              5
     577              4
     578              4
     579              5
     580              4
MEMMAT
       0   .7469        0   .9999
   .7378       0    .9999       0
       0   .3661        0   .9999
   .3361       0    .9999       0
MEVEC
   .9365   .8631    .8697   .6749
   .9488   .8810    .8921   .7398
   .9588   .9253    .9246   .7999
   .9999   .9999    .9999   .9999
     581              6
     582              4
     583              3
     584              3
     585              5
     586              3
     587              4
     588              4
     589              4
     590              6
     591              3
     592              5
     593              5
     594              4
     595              5
     596              3
     597              4
     598              3
     599              4
     600              4
MEMMAT
       0   .7463        0   .9999
   .7396       0    .9999       0
       0   .3311        0   .9999
   .3421       0    .9999       0
MEVEC
   .9460   .8836    .8892   .7061
   .9564   .8987    .9082   .7613
   .9649   .9364    .9358   .8298
   .9999   .9999    .9999   .9999
```

601	4
602	4
603	4
604	3
605	4
606	3
607	4
608	4
609	4
610	4
611	4
612	4
613	4
614	4
615	5
616	4
617	3
618	3
619	4
620	4

MEMMAT

0	.7460	0	.9999
.7210	0	.9999	0
0	.3254	0	.9999
.3544	0	.9999	0

MEVEC

.9502	.3925	.8978	.7289
.9598	.9066	.9153	.7798
.9677	.9413	.9408	.8430
.9999	.3999	.9999	.9999

621	4
622	4
623	3
624	3
625	4
626	4
627	3
628	3
629	4
630	4
631	4
632	3
633	4
634	4
635	4
636	3
637	3
638	3
639	5
640	4

MEMMAT

0	.7657	0	.9999
.7235	0	.9999	0
0	.3577	0	.9999
.3661	0	.9999	0

MEVEC

.9540	.9009	.9057	.7499
.9629	.9133	.9219	.7969
.9702	.9459	.9454	.8552
.9999	.9999	.9999	.9999

641	3
642	4
643	4
644	4
645	3
646	3
647	5
648	3
649	3
650	4
651	4
652	3
653	3
654	3
655	3
656	4
657	3
658	4
659	4
660	3

MEMMAT

0	.7349	0	.9999
.6789	0	.9999	0
0	.3363	0	.9999
.3804	0	.9999	0

MEVEC

.9593	.9123	.9165	.7785
.9671	.9237	.9308	.8201
.9736	.9521	.9516	.8717
.9999	.9999	.9999	.9999

661	4
662	4
663	4
664	3
665	3
666	4
667	4
668	4
669	4
670	3

671	3
672	3
673	3
674	4
675	3
676	3
677	3
678	3
679	5
680	4

MEMMAT

0	.7358	0	.9999
.7038	0	.9999	0
0	.3107	0	.9999
.3705	0	.9999	0

MEVEC

.9624	.9191	.9230	.7957
.9697	.9296	.9362	.8341
.9756	.9559	.9554	.8817
.9999	.9999	.9999	.9999

681	4
682	4
683	3
684	3
685	4
686	4
687	4
688	3
689	3
690	3
691	4
692	4
693	4
694	3
695	3
696	3
697	4
698	4
699	4
700	3

MEMMAT

0	.7563	0	.9999
.7268	0	.9999	0
0	.3054	0	.9999
.3417	0	.9999	0

MEVEC

.9654	.9253	.9289	.7923
.9720	.9351	.9411	.8277
.9775	.9592	.9599	.8908
.9999	.9999	.9999	.9999

701	3
702	4
703	4
704	4
705	3
706	4
707	4
708	3
709	4
710	3
711	4
712	4
713	3
714	4
715	4
716	3
717	4
718	3
719	4
720	3

MEMMAT

0	.7864	0	.9999
.7629	0	.9999	0
0	.2651	0	.9999
.2966	0	.9999	0

MEVEC

.9699	.9352	.9383	.8197
.9757	.9435	.9489	.8504
.9305	.9645	.9643	.9052
.9999	.9999	.9999	.9999

721	3
722	3
723	4
724	3
725	4
726	3
727	5
728	3
729	4
730	3
731	4
732	4
733	4
734	3
735	4
736	3
737	3
738	4
739	3
740	4

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MEMMAT
      0   .8200       0   .9999
  .7805       0   .9999       0
      0   .2253       0   .9999
  .2701       0   .9999       0
MEVEC
  .9744   .9449   .9475   .8266
  .9793   .9520   .9565   .8528
  .9834   .9693   .9696   .9194
  .9999   .9999   .9999   .9999
    741               4
    742               3
    743               3
    744               3
    745               3
    746               3
    747               4
    748               3
    749               4
    750               4
    751               4
    752               3
    753               4
    754               4
    755               3
    756               4
    757               3
    758               3
    759               4
    760               4
MEMMAT
      0   .8173       0   .9999
  .8016       0   .9999       0
      0   .2033       0   .9999
  .2441       0   .9999       0
MEVEC
  .9769   .9502   .9526   .8433
  .9813   .9566   .9607   .8669
  .9850   .9728   .9725   .9271
  .9999   .9999   .9999   .9999
    761               4
    762               3
    763               4
    764               4
    765               5
    766               4
    767               3
    768               4
    769               3
    770               3
```

```
 771         4
 772         3
 773         4
 774         4
 775         3
 776         4
 777         4
 778         4
 779         3
 780         4
MEMMAT
     0   .8414       0   .9999
 .8278       0   .9999       0
     0   .1770       0   .9999
 .2119       0   .9999       0
MEVEC
 .9799   .9567   .9588   .8639
 .9838   .9624   .9659   .8845
 .9870   .9763   .9761   .9367
 .9999   .9999   .9999   .9999
 781         4
 782         3
 783         3
 784         4
 785         4
 786         4
 787         4
 788         3
 789         3
 790         4
 791         4
 792         4
 793         4
 794         4
 795         4
 796         4
 797         3
 798         3
 799         4
 800         4
MEMMAT
     0   .8507       0   .9999
 .8379       0   .9999       0
     0   .1666       0   .9999
 .1994       0   .9999       0
MEVEC
 .9811   .9593   .9512   .8331
 .9847   .9646   .9679   .8912
 .9877   .9777   .9775   .9404
 .9999   .9999   .9999   .9999
```