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INFORMATION FLOW IN TASK-ORIENTED GROUPS

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Abstract

Chapter I: A nonaction-quantized group experiment in which the subjects were conditioned in one communication network and tested in another is described. The difficulties of this general information flow problem are pointed out.

Chapter II: The group results for time, number of messages, content of messages, and errors are presented. It is shown that interesting carry-over effects occur; that the dominant effect is that of the present communication network.

Chapter III: Individual decisions are characterized in terms of conditional probabilities for certain ambiguous and unambiguous conditions. Rational behavior is found under unambiguous conditions, but the determinants of behavior in the ambiguous situations are not well understood.

Chapter IV: It is shown that individual decision times and probabilities of decision are not directly interdependent; that both depend on the information state. The exponential distribution is again found adequate for individual decisions and it is shown that the decision rate is nearly constant for serial decisions.

Chapter V: Subjects' knowledge of the network and their attitudes toward experiences in the groups are examined and explanations in terms of the problem situation and previous network experience are given.

Chapter VI: Conclusions from this and previous studies are drawn, and generalizations are made concerning future developments and applications.

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INFORMATION FLOW IN TASK-ORIENTED GROUPS*

Chapter I. MOTIVATION AND DESIGN OF THE EXPERIMENT

1. INTRODUCTION

The work discussed in this report covers the first major experiment completed by the Group Networks Laboratory after the experiments described in Technical Report No. 231 (1). We shall assume that the reader is familiar with that report, and we shall not discuss the historical and general motivational background of this experimental program.

The principal experiment discussed in Technical Report 231, the action-quantized number experiment, was severly restricted in two ways: (a) The subjects were instructed to send one message each at the same time, the time being determined by the slowest subject in each "act." (b) The message content was restricted to problem information only; that is, to messages of the form, "From A to B, subject C has n as an input number."

These two restrictions led to simplifications in the analysis that allowed a more detailed understanding of the communication process than had been possible heretofore. They may be summarized as: (a) The time needed to decide on the destination of a message, and to prepare it, was independent of the decision itself; consequently, these two aspects of the problem could be analyzed separately. (b) The number of acts to complete a trial formed an objective criterion of the quality of the group performance. Using this criterion, it was possible both to motivate the subjects to optimize their decision behavior in a well-defined way and to carry out the analysis of their behavior in terms of changes in this variable. (c) The elimination of nonproblem messages allowed the data to be analyzed in terms of the task alone, without concern for the subtle and important modifications introduced into the problem-solving behavior when "extraneous" messages are present.

Because of these factors the detailed analysis of the problem-solving behavior, relating the measured individual performance via the relations imposed through the communication network to the measured group performance, was in large part successful and certainly more complete than any other published work. This led us to believe that certain aspects of the process are more dominant than others. We concluded that the most advisable next step was to relax some of the conditions under which the first

*This experiment was a joint effort of the Group Networks Laboratory and Dr. D. Harvie Hay, Department of Economics and Social Science, M.I.T. The first report of the work is Dr. Hay's doctoral thesis, submitted in June 1953. Although the present report is in some part based on the thesis, Dr. Hay is not to be held responsible for the opinions expressed here, since the viewpoint is different and much of the analysis was pursued further than in his thesis, and the actual writing of the report was done after Dr. Hay left the Institute.

experiment was run and to attempt the analysis of the resulting more complicated experimental situation by using the insight obtained from the action-quantized case.

The study was executed during the winter of 1951 and the spring of 1952, and the reduction of data and its analysis was continued through the spring of 1953. The results, organized in a manner similar to that of Technical Report No. 231, are presented in this report.

2. THE PRINCIPAL FEATURES OF THE STUDY

Before describing the detailed design of the experiment (see sections I. 4 and I. 5), we shall point out the broad features of the study and the accompanying difficulties.

A. We decided to remove the restriction of action quantization, although we were well aware that it had been this condition, in large part, that had allowed the relatively complete analysis of the previous experiment. It was felt that if we could retain to some degree its simplifying features we would have a greater likelihood of concluding a penetrating analysis of the group behavior. We therefore required that the subjects send messages only at regular intervals. Mathematically, this condition significantly reduces the number of possible ways in which the group can solve the problem, as compared with the completely free case, and permits us to determine, in most cases, what information a man considered when he wrote a message.

B. The restriction of message content to problem information only was removed and the subjects were allowed to communicate (in writing) anything they chose. This generalization creates three problems: the analysis of the problem messages in the presence of nonproblem messages; the analysis of the content of nonproblem messages; and the study of the flow of nonproblem messages.

C. We felt that while carrying out an experiment embodying A and B, and without jeopardizing the potential results stemming from it, we could introduce a parameter not previously studied: the effect of relatively short time experience in one network on the subsequent performance of the same group in another network. With respect to this variable the following questions are of interest: Is there only a short term carry-over, or is it lasting? Does the carry-over affect all phases of the group's activities or only a part of them? Does there appear to be a pattern to these effects? If there is such a pattern, can it be formalized? It should be emphasized that we are not looking for the carry-over effect in changing a hierarchical system, or one of long standing, or one evoking strong emotional reactions, but, rather, the simple operational carry-over from experience in one network to another.

These are the three principal features of the experiment that distinguish it from its predecessor. The experimental technique, as we shall see, is substantially the same, but the procedure of analysis has been modified appreciably.

3. THE PRINCIPAL DIFFICULTIES OF THE STUDY

Several basic difficulties arise in group experiments of the sort described here; some are old and familiar, others were encountered for the first time. It seems worthwhile to mention them briefly, to indicate the approach taken, and to evaluate the technique.

A. The design of a tool for measuring the reactions of the subjects to the experimental situation.

As in the past we used a questionnaire (Appendix 2) for this purpose. However, the previous questionnaires were intuitively constructed, whereas the one in use here was designed on the basis of factor analyses of earlier ones. This will be described more fully in chapter V. We believe that a considerable improvement was achieved over previous questionnaires.

B. The interrelation of instantaneous emotional reactions with the problem-solving behavior.

This is a problem of fundamental difficulty, since there seems to be no way in which we can make measurements of individual transient emotional states without utterly destroying the natural flow of problem messages. One conjecture is that the content of nonproblem messages could be used for this purpose, but the relatively low frequency of these messages when the communication is written makes this impractical. Whether this method will be more usable with oral communication in task groups remains to be seen. Since we had no usable method of measuring these emotional states, we elected to ignore the interaction and to attempt to deal with the problem messages as though the subjects remained emotionally invariant over time.

C. Criteria of performance.

As in the previous experiment, the problem given the group was so simple that errors are not a significant feature of the group performance and hence they cannot be used as a criterion. As we have pointed out, the acts to complete a trial were used both to motivate the subjects and as a primary parameter of analysis in the previous experiment. To use exactly the same procedure again is impossible. The nearest equivalent to an act is the number of time units taken to complete a trial. There is a definite minimum to this parameter for each network (it equals the minimum number of acts required with action quantization), but since the subjects were not told what this minimum is they had a less definite goal than before. Also subjects are probably less sensitive to changes in the number of time units than to changes in the number of acts per trial, since, on the average, the former was more than double the latter. With respect to analysis, the number of time units is a very complex composite of the individual decisions and the times to reach those decisions, so that, in contrast to the action-quantized case, decision time cannot be neglected in any theory that predicts the over-all group time per trial from the behavior of individuals. Such a theory remains an unattained goal although we believe that major fragments of it are contained in the following pages.

We have, therefore, used group time only as a gross and unanalyzed criterion and have devoted most of our effort to examining the details of individual behavior.

D. The measurement of individual performance.

As in the past our primary data about the individuals are the message cards with their source, their destination, and the time of sending appended. It will be recalled that in the action-quantized case it was possible to summarize the performance of the group completely and very simply. Each act of each trial was completely represented by a 5×5 matrix with entries 0 and 1. To describe the individual behavior we presented various conditional probabilities, and the isolation of several relatively simple but adequate conditions from the tables of matrices was not an overwhelming job.

Without action-quantization there is no such simple representation of the data; an explicit time parameter must be considered rather than a simple ordering of acts. Therefore, this question arises: Given such message cards, how can we ascertain the various conditional probabilities in which we might be interested? It became fairly clear that this would be very difficult to do "by hand" as the analysis was done in the past. The alternative that suggested itself was I. B. M. processing.

The function of I. B. M. equipment is, basically, to compare entries on single cards and to count the cards that fall into certain classes; it is not to relate one card to another. The basic feature of the group process is the dependence of a message on a (presumably small) number of preceding messages, their sources, and their destinations. In order to use I. B. M. equipment it is necessary to place on a single card the relation of that card to the relevant preceding messages so that the desired information can be reduced to a counting procedure. The difficulty is that since there are but 80 columns on an I. B. M. card not all of the many relations with past messages can be tabulated. It was clear that to be practical an attempt would have to be made to break down the relations into "components" out of which several more complex past relations could be constructed within the limitations of the I. B. M. machinery. This is possible because of the operation of comparison of two columns on single cards. Indeed, if this were not possible, then I. B. M. processing would be of no value; for the relations that are placed on the cards must be detected by human operations on the message cards themselves.

Thus we see, first, that a great deal of human labor is required to study these aspects of group performance before they can be reduced to machine counting. About ten man-months were required to reduce the data contained on 17, 500 out of a total of approximately 40, 000 message cards.

Second, the use of this method requires advance knowledge of exactly what questions will be asked of the data and exactly what conditions must be punched on the cards to answer these questions. Since only a very limited number of relations can be described on a card, the choice of those to be used must be made carefully. To make the choice, either one must have a theory (at least a usable hunch) as to which relations are significant or one must take a very small preliminary sample of the experimental data and process it until he is satisfied that the significant relations have been found. Since the latter procedure is very nearly impractical because the frequencies become exceedingly low in any reasonably small sample, we elected to use the former, basing our guesses as well as we could on the results of previous work.

For experiments such as the one we are discussing, this method of analysis is just barely useful. It could easily waste a great deal of time and money but with proper use it produces results. For very complicated situations it will almost surely get out of hand if it is used directly. On the other hand, if a theory can be evolved through experiments such as this, and if the conditional probabilities are not too complex, the coding of their conditions into a form suitable for I.B.M. processing is possible. If the significant conditions reach far into the past, the computational labor is excessive, as is known from a simple calculation and from experience in computing conditional entropies of language. One of the main contributions of this and the preceding studies is to suggest, and to some extent to document, that while these conditional relationships are quite complicated they may just be within the reach of current methods of data-handling and analysis.

4. THE DESIGN

The basic design is similar to the design used in our earlier experiments. Groups of five naive subjects participated in a series of 30 similar trials, which were broken into three phases, the first phase consisting of 5, the second of 10, and the third of 15 trials. Each phase was followed by the same questionnaire (Appendix 2). The first set of five trials, on the network Pinwheel (Fig. I. 1), was run to permit the subjects to become familiar with the mechanics of the problem and apparatus. Pinwheel was chosen because past experience indicated that there is very little possibility for an organization to be formed in that network in so few trials. The following ten trials were on one of the four networks shown in Fig. I. 1, and the final 15 trials were, in all cases, on Diablo. The latter set of trials is known as the test phase, and the middle set as the conditioning phase, of the experiment. Mainly because of time limitations, chapters III and IV of this report are concerned with the test phase only. In all, there were six experimental configurations and ten groups were run on each configuration. The configurations differ only in the network used in the conditioning phase or in its relation to Diablo in the test phase. Both Star and Diablo have a central position, the other nodes — called peripheral — being logically equivalent, and so in the transition from one of these networks to Diablo there are two variations: the central man may remain in

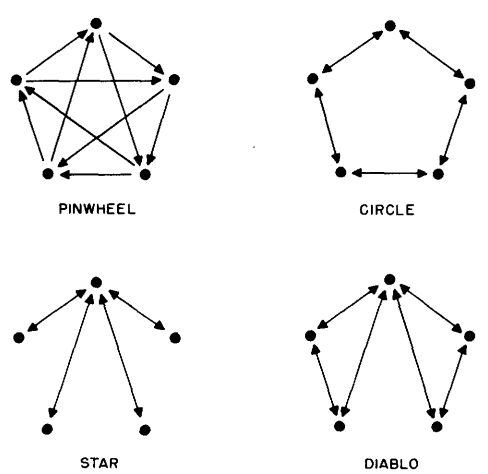

Fig. I. 1
Networks studied in the experiment.

the center, or he may be moved to a peripheral position. We denote the former by an unprimed symbol, the latter by the same symbol primed. Thus, we may label the experimental configurations by C, P, S, S', D, D' (we shall use this notation throughout the report). Except for D (which was not changed) and P, there are several ways in which the transition could be made from the conditioning to test phase; we chose a way involving a minimum change in links, as shown in Fig. I.2.

The task confronting the subjects in all trials was the same as that in the action-quantized experiment: each subject had, as an input, a single number between 0 and 99 and the group concluded a trial when each subject knew what inputs were given the other subjects and had signalled this knowledge to the experimenter.

Following instructions (Appendix 1) which described the problem and the use of the apparatus and motivated the subjects to speed, they were seated at a round table similar to those previously used (with modifications to be described), and the experiment was executed in the presence of an assistant who prevented nonwritten communication, administered the questionnaires, and answered questions pertaining to the use of the equipment. The duration of each experiment on a single group was approximately 2.5 hours.

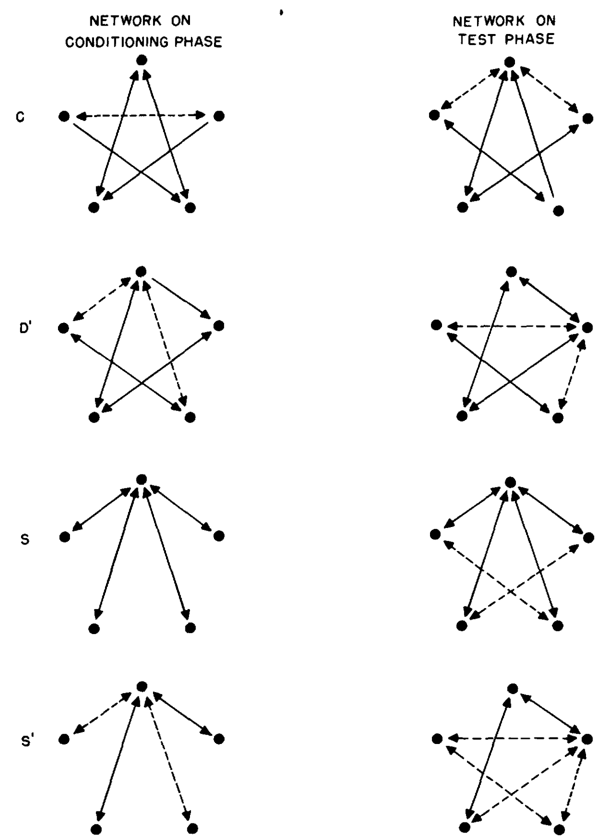

Fig. I.2

Network change. The solid links remained invariant, the dotted ones were changed.

The only modifications to the table used in the action-quantized experiment were (a) to remove the ready button, (b) to add a red light to each answer button, which served either to reassure the subject that he had pushed the button or to remind him to do so, and (c) to modify the center post so that the times at which messages passed through each of the slots were recorded.

In a nonquantized case one difficulty is to attach the time of message sending to the cards. Our solution was to number serially the cards given each subject and to record the times at which each channel was used. Since the cards were labelled as to sender before the experiment and as to receiver following its completion, this allowed us to identify the time of sending of each card. To record these times we introduced a contact switch in each of the 20 channels in the center post and wired each switch to a pen of an Esterline-Angus recorder. The answer buttons were also attached to the recorder.

An audio oscillator and amplifier were used to sound a 400-cps tone for a duration of 3 seconds, every 15 seconds. It was during the 3-second sounding of the tone, and then only, that the subjects were allowed to send messages.

The subjects were drawn from two populations: Navy enlisted personnel from the Receiving Station, First Naval District, Boston; and Army enlisted personnel from the Reception Center, Fort Devens, Ayer, Massachusetts. These populations were divided evenly over the experiment so that five groups in each configuration were Army subjects and five were Navy. We hoped that it would be possible to lump the results from these two populations in all cases; but since this was not possible in every case a few of the frequencies are unfortunately low.

5. THE DATA AND THEIR ANALYSES

The data taken fall into three categories: the three sets of questionnaires, the Esterline-Angus time record, and the message cards themselves. The last two were immediately combined; each card was labelled with an integer representing the number of elapsed time units from the beginning of the trial to the time the card was sent.

As we pointed out in section I. 3, one of the problems in preparing the cards for I.B.M. processing was to decide what of the past history should be included on the cards. The following statement indicates all the information that was included for the last 15 trials, though not the particular method of coding.

A. General identification: experiment number; Army or Navy subjects; network configuration; identification of the center position, if any, in the middle phase; identification of the center man in the final phase.

B. Specific identification: identification of the sender (call him X); identification of the receiver (call him Y); the network relation of these two men in terms of past and present networks; the number of the trial; the number of the card within the trial; the time unit on which the card was sent; the information present at X, in terms of which men's inputs he knew at the time the message was sent; what input information this message added to Y; whether or not X was left-handed.

C. Content of the message: The content of the message was reduced to one of eleven categories (one message card may fall into more than one of these categories):

1. Problem information: a statement of whose inputs are described on the card.

2. Any request for information about the inputs to the subjects.

3. Any request for information about the network, that is, what communication channels are open or closed.

4. Any information sent about the network.

5. Any directions or instructions sent concerning the completion of the problem, such as "send this on to A" or "pass me your information first."

6. Any directions or instructions requested concerning the completion of the task.

7. Any expression of aggression about either the experiment, the procedure, or the experimenter.

8. Any expression of aggression toward the receiver of the message.

9. Any expression of aggression toward a member of the group other than the receiver.

10. Any expression of encouragement such as praise for speed or cooperation, or friendly remarks such as "You are doing fine."

11. Any other content not falling into one of the above categories.

D. History of incoming messages: a list of the people from whom messages had been received between X's last sending and the present card; the total content of these messages, except those received from Y, in terms of whose inputs they described; the total input content received from Y; the time of the latest incoming message.

E. History of previous outgoing message: the man to whom X's previous message was sent; the information X had about the inputs at the time of sending it; the time at which it was sent.

F. History of previous messages to Y: the input content of all previous messages in the present trial from X to Y; the number of people who sent messages to Y.

Very nearly the same analysis could be conducted for the conditioning phase but because of time limitations it was not done. Thus, most of the following discussion, except the group results, will be based on the last 15 trials.

Chapter II. GROUP PERFORMANCE

1. GROUP TRIAL TIMES

The time taken to complete each task is a criterion of the excellence of a group's performance, for the subjects were instructed to complete the experimental tasks as quickly as possible. These instructions did not run counter to their natural desires, which further recommends the time per trial as an indicator of the quality of performance. Since we are concerned with differences among groups run under the various experimental conditions and not with the differences among groups within one condition, we shall study only the central tendency of the groups run under the same conditions. However, our subjects were, as a matter of practical necessity, drawn from two populations that differ in respects that are relevant to the tasks they performed: the Navy groups were somewhat more rapid and efficient than the Army groups. This, and the skewness of the time distributions, must be considered in selecting a statistical treatment of the data.

The mean, which usually has desirable sampling properties, is very unstable in small samples from skewed distributions. We may meet this problem in one of two ways. First, the variate may be transformed so that the distribution becomes approximately normal. How well this can be effected depends on how accurately the shape of the original distribution is known. It is not well known from our data. Second, some measure of central tendency may be used which, unlike the mean, avoids an undue influence of the extreme values. We are forced to this solution; the measure we shall use is the median.

A median based on all ten groups in one condition includes both Army and Navy groups, and, as we pointed out above, these two populations differ in such a way that the median will be estimated from a sample having a very flat central region. This is undesirable; to circumvent it we have calculated the Army and Navy medians separately and then taken the mean of these two values. It can be shown that, under the conditions we have, this statistic has a smaller expected standard error than the over-all median. Empirical tests on the data confirm this theoretical expectation and also show that the stability of this statistic is much better than that of the mean.

The price paid for using the median is the impossibility of conducting an analysis of variance to demonstrate the significance of differences in our data. This is unfortunate but unavoidable, since we shall be most concerned with time trends, which can be seen most clearly only when the most stable available statistic is used.

Data points and trend lines for the first two phases of the experiment are presented in Fig. II.1. In the conditioning phase there were 20 groups each on the networks Star and Diablo, ten of which became primed groups (center changed) and ten unprimed, in the test phase. The ten Circle groups and the ten Pinwheel groups have been combined, since separate plots of the time data were indistinguishable. The trend line for the first five trials is an average over all groups, which is permissible, since only the

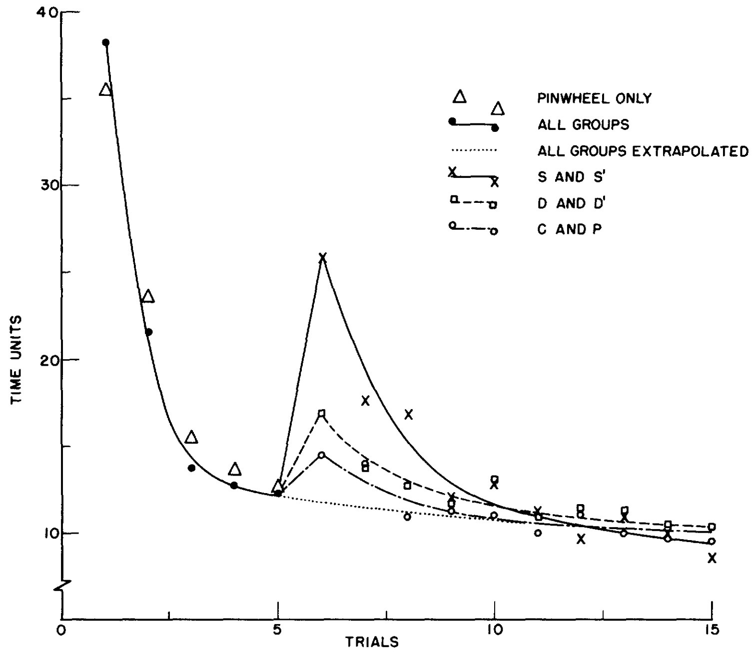

Fig. II. 1
Time by network (first and conditioning phases).

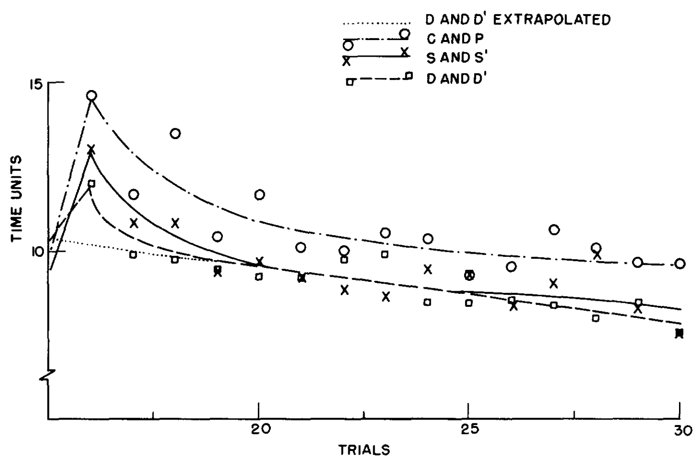

Fig. II. 2
Time by configuration (test phase).

network Pinwheel was used in this phase. It is notable that from trial 3 on, the slope of the trend line is shallow, which is evidence that the desired training was realized in the first phase.

The rise in the Circle-Pinwheel curve at the beginning of the conditioning phase can be interpreted as an effect of the interruption between the two phases and the interpolated questionnaire activity. The subsequent drop can be described as a warm-up effect. The Star and Diablo groups, particularly the former, show a much larger rise on trial 6, followed by a drop, which in the case of the Star groups has fallen slightly below the trend of the other groups by trial 15. These differences must be attributed to the effect of the new network.

A smooth extrapolation of the apparent trend of all groups during the first five trials is shown in the figure, and the Circle-Pinwheel trend line fairs nicely into this extrapolation by trial 10. All groups have a central tendency of approximately ten time units per trial at trial 15.

The corresponding time data for the test phase are presented in Fig. II.2. Since all groups are subject to the communication network Diablo during these trials, the classification of groups rests on their differential history in the conditioning trials. As before, the C and P groups have been combined, since their time records are practically identical. The expectation of differences between S and S' and between D and D' has been realized in some respects, but not in the gross group time record, so again they have been combined.

An extrapolation of the Diablo trend line from the conditioning phase has been included, and the D-D' trend line for the final phase fairs into it very quickly. The rise and subsequent drop following trial 16 can again be attributed to interpolated activity between the phases and to a warm-up effect. It is noteworthy that the S-S' and C-P groups both show a greater jump above the extrapolated Diablo curve than do the D-D' groups, though the rises are less than those that occurred at trial 6. A difference is that the C-P groups maintain a relatively high value throughout the test phase.

The networks fall into three classes defined by the degree of centralization: Circle and Pinwheel have no central node; Diablo has a center located between two internally connected sides; and Star has a center without which the remaining members would be totally disconnected. At trial 6 the degree of disturbance increases in the order Circle-Pinwheel, Diablo, Star; that is, it increases with increasing centralization. At trial 16 the order of increasing disturbance is Diablo, Star, and Circle-Pinwheel. This suggests that the severity of the disturbance depends upon the extent of the difference in centralization between the pre- and post-change networks.

2. NUMBER OF MESSAGES

The time for completing a trial can be considered as being composed of two factors: the speed at which messages are sent and the pattern or sequence of sendings. The former certainly increases as the individuals learn the mechanics of the problem; they may be expected to learn most within the first few trials. It will also increase as a subject is more certain where he should send his messages, which, in turn, reflects the adequacy of the pattern of message sending that has evolved. The effectiveness of such patterning is a direct reflection of group organization, and therefore it would be desirable to have a measure of the effectiveness of the message-sending decisions.

It is clear that there is a strong correlation between the time for completing a trial and the number of messages required, but whereas time is affected both by the organization of the group and the rapidity of writing, the number of messages reflects only the organization. This suggests that in this experiment the number of messages is a suitable measure of the gross organization of the group.

In chapter III the quality of the groups' organization will be carefully analyzed in terms of the behavior of the individuals in the group. Here we are concerned with showing that there is an improvement in organization over trials and a difference between networks which the later analysis will serve to explain. In Fig. II.3 the number of messages per group is plotted as a function of trials for the first two phases of the experiment. The curves are smoothed trend lines and the points are means of the Army and Navy medians. The reason for using this statistic is the same as in the case of the time data. The data for the groups run on Pinwheel during the conditioning trials have been plotted separately from the over-all average for the first five trials. These data are shown to be reasonably well fitted by the over-all trend line. The trend line for the first phase has been extrapolated into the conditioning phase to provide a reference level with which to compare the later performance. Circle and Pinwheel have been lumped

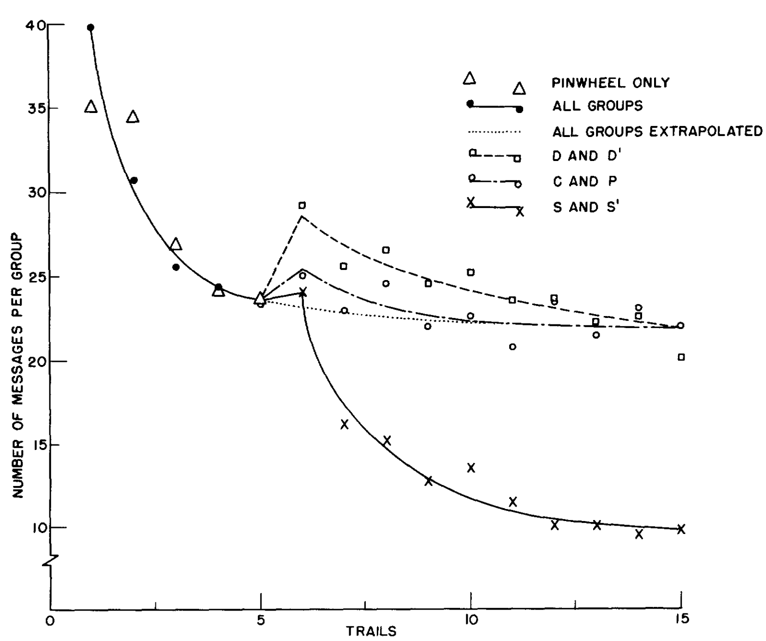

Fig. II.3

Messages by network (first and conditioning phases).

again because the separate curves were essentially the same.

For the first five trials the character of the data on number of messages is similar to the time data for the same period. They differ in the extent of the drop, in the steepness of the curves, and in the sharpness of curvature. These differences are reasonable, since the time for completing a trial is decreased by both mechanical learning and organizational improvement, whereas the number of messages is decreased only by the latter process.

The curves for Diablo and Circle-Pinwheel during the conditioning trials are similar to their time records. Following trial 5 the latter curve shows a small rise which subsequently fairs into the curve extrapolated from the first five trials. The Diablo groups show a larger rise which falls away at a slower rate, reaching the level of the Circle-Pinwheel curve only at trial 15. Its slope, at this point, is larger than that of the Circle-Pinwheel curve and it appears that it would have gradually dropped below that curve if further trials had been run without a change of network. The behavior of the D and D' groups on trials 16-30 supports this contention, as can be seen in Fig. II. 5. For the Star groups there is much less similarity between the message and time records. The message curve starts at very nearly the same value as the all-groups-average on trial 5 and it drops sufficiently rapidly that by trial 16 the Star groups are using less than half as many messages as any other groups.

The discrepancy between the message and time plots for Star groups is readily explained. The Star network forces one man to be central and the remaining men to depend only on him. As we shall see (chapter III), except for the first message of a trial, message sending behavior is very reasonable. The greatest problem, in general, is selecting the destination of the first message of a trial. But in Star this is no problem for the peripheral men, and it is immaterial what the center man does; that is, the network rigidly enforces the best possible (for the network) first-message organization. The peripheral subjects soon realize that their first message contributes all that they can contribute to the distribution of information and they tend to send relatively few other messages, thereby causing the rapid drop in messages sent for the whole group. On the other hand, the center man, once he has received the input information for each of the others, must send to each of them. Thus, the group time depends largely on his behavior; whereas in other networks the work is more evenly spread, and the total time commonly depends on the slowest man in the group. We should, therefore, expect only small differences in group time between Star groups and groups in other networks.

The observed behavior of the groups can be discussed in terms of certain optimal possibilities. For no network on five nodes can the experimental task be completed in less than three time units; for some the minimum number at time units may be as many as five. For Circle, Pinwheel, Diablo, and Star the minima are three, three, four, and five, respectively. With respect to messages, the minimum number is eight for all connected five-node networks. It is easy to see that in many cases the use of minimum messages cannot result in minimum time, and since the time minimum was emphasized in the instructions we must consider it the more important. We may, however, still discuss the efficiency of the group in terms of messages by defining a conditional minimum for messages – one subject to the requirement that the problem be completed in minimum time for the network used. These conditional minima are: for Circle and Pinwheel, 14; for Diablo and Star, 8. The message data for the first 15 trials have been replotted in terms of the number of messages exceeding the conditional minimum (Fig. II. 4). The three classes of groups behaved in radically different ways in their approach to maximum efficiency: in Star there is a rapid approach to nearly perfect performance; in Circle and Pinwheel a very slow trend with a moderately good level of performance is found; and Diablo shows a moderate trend, but has the poorest approximation to ideal performance.

There appears to be a compensatory relation between the minimum for a given network and the severity of the demands on the organization of the group that are necessary to attain that goal. Thus, a Star group can do no better than five time units per trial, but its chances of doing so are good. Circle and Pinwheel groups potentially can do the task in three units, but to do so the members of the group must choose correctly the destination of almost every message they send. Diablo is intermediate in both respects, but in actual performance Diablo groups do worst in realizing the possibilities.

In the test phase, any differences in organization, as expressed in number of messages, must reflect a carry-over from experience on the conditioning trials. These differences, presented in Fig. II. 5, are not large, but they do show a definite pattern. The curve for the D and D' groups shows a slight jump at trial 16, but very shortly resumes the trend of Diablo from the previous trials until trial 24 or 25, when the slope of the curve steepens. Circle and Pinwheel lie very close to Diablo throughout the conditioning trials, but in passing to Diablo, on trial 16, there is a much greater jump in the former two and only a very little increase in slope at the end of the set of trials. The groups that had their conditioning experience in Star are distinctly split off from the other groups. The curve of S and S' runs very nearly parallel to, but at a level approximately six and one-half messages per trial less than, the C-P curve. Its difference from the D-D' curve is not as great and is more variable, but the difference is nonetheless striking, since there is not a single crossing of the curves. The effects may be summarized by saying that Circle and Pinwheel, as the conditioning experience, have a very slight effect on the performance in Diablo, and what effect they do have is detrimental compared to the effect of Diablo as the conditioning network. Experience on Star has a definite beneficial effect. Modes of behavior appropriate to Star are sufficiently similar to those appropriate to Diablo that this result was anticipated. It is possible that this carry-over effect from Star might ultimately prove deleterious, since a Star-like performance in Diablo will be good – but not optimum.

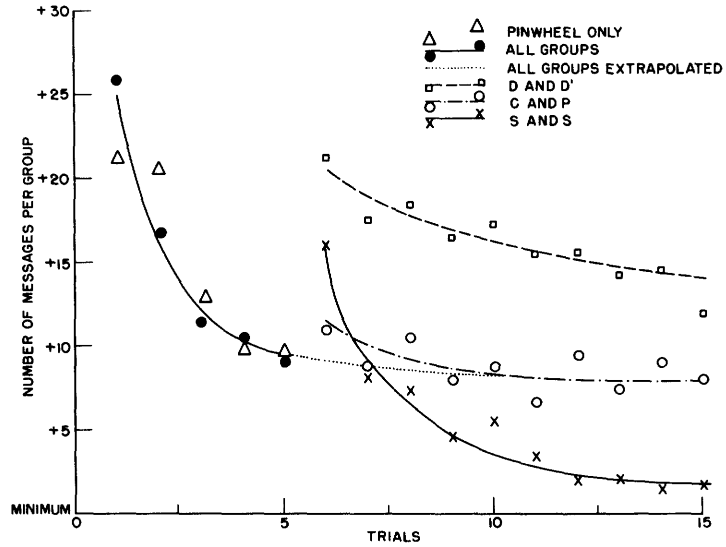

Fig. II. 4

Messages sent compared to the conditional minimum.

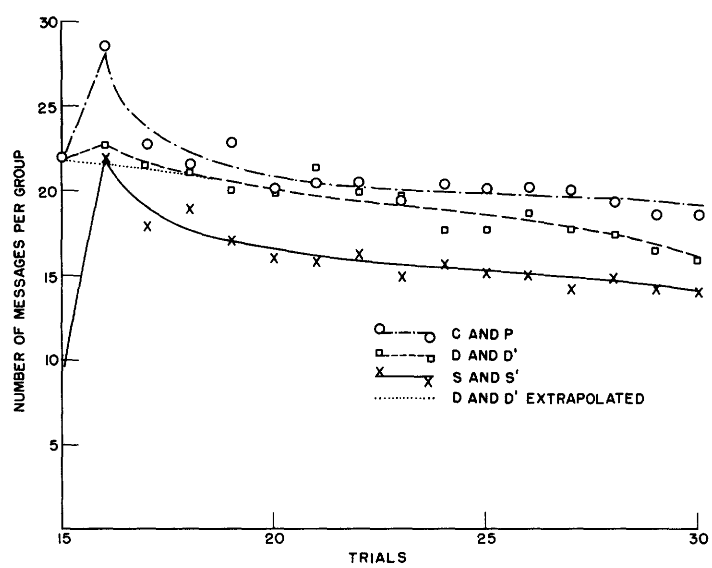

Fig. II. 5

Messages by configuration (test phase).

3. TIME PER MESSAGE

We turn now to the second factor from which the total group times are composed, the time per message. It is clear that the mechanical learning in the early trials should be most accurately reflected in this measure, and if the intention of the first phase of the experiment was realized, the major part of the change in the measure should be concluded by trial 5. This appears to be true, as shown in Figs. II.6 and II.7. The quantity plotted is the ratio of message sending opportunities to number of messages sent in the trial, using the mean of the Army and Navy medians in both cases. The data for the first five trials, the trend line extrapolated through the conditioning phase, and the curve of Circle-Pinwheel, are presented in both figures as a common reference.

As in our earlier discussion, it would be well to have a measure of optimal behavior with which we may compare the data. The ratio of the minimum number of time units for the network to the number of messages required of a subject when the group is using the conditional minimum of messages seems appropriate. It is clear that since we average all men in a given type of position it will be necessary to perform the same sort of averaging in this definition. Nonetheless an ambiguity exists; for with some networks, such as Diablo, there are several different patterns of message sendings that achieve optimal time in minimum number of messages but do not have the same average ratios within each type of position. When no ambiguity exists we shall call the average ratio the ideal time per message; when there is an ambiguity the ideal time will be defined in relation to a particular pattern of message sendings.

The peripheral subjects in Star show a very large jump in time per message at trial 6 and only a very slight drop from this value over the conditioning trials. All the data points lie above the ideal value (which is unique) but there is some trend toward it. We note there is a considerable difference between the peripheral and center subjects of Star. The most striking fact about the record of the peripheral subjects is that the jump is immediate and therefore represents the role forced upon them by the position they occupy.

The change from trial 5 to trial 6 is greater for Star center subjects than for Circle-Pinwheel subjects. One can conclude that the change in role of the Star center positions produces a greater disturbance than that produced by interpolated activity alone. Subsequently, the curve drops toward the Circle-Pinwheel curve and by trial 15 seems to be crossing it, which suggests that if further trials had been run, the Star center curve would have gone below the Circle-Pinwheel curve. However, the unique ideal time per message is 1.25, which is greater than the unique ideal value of 1.10 for Circle and Pinwheel. Therefore, if the time per message of the latter groups approaches its ideal value it must eventually recross the curve of the Star center subjects. The fact that it does not cross it in ten trials is a further reflection of the fact that Star is able to realize its potential much more rapidly than are the other groups.

The similarity of the time per message data for Star center and Pinwheel-Circle

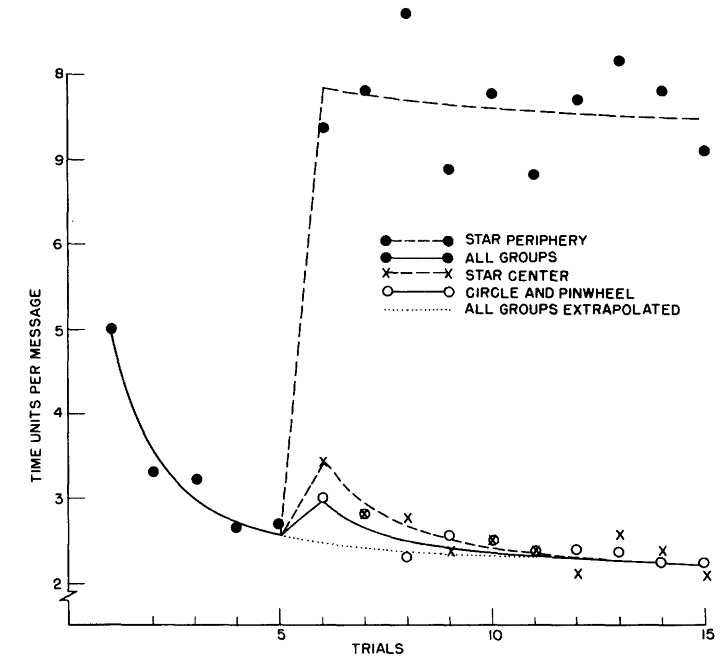

Fig. II.6
Time per message by position (first and conditioning phases).

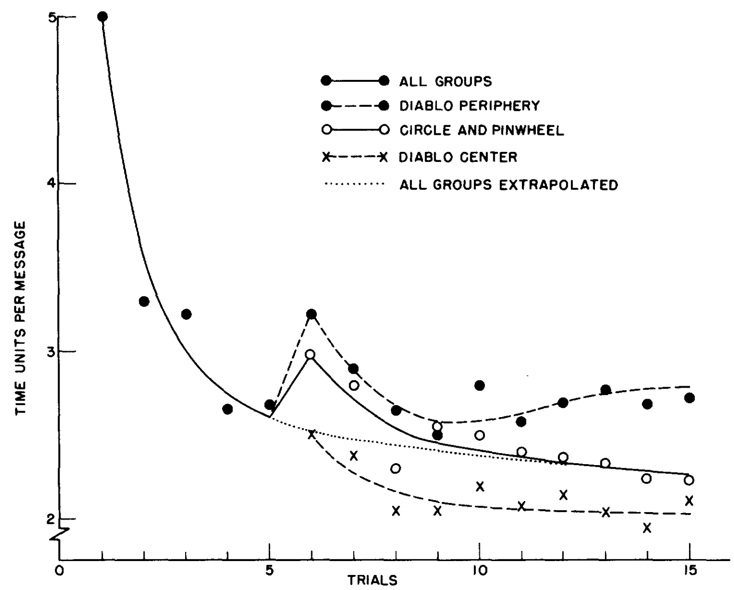

Fig. II.7
Time per message by position (first and conditioning phases).

supports the earlier contention that their time records are nearly equal during the conditioning trials because the time per trial for Star groups is largely determined by the behavior of the center men.

In Diablo, Fig. II.7, we see that position has a less striking effect on behavior than in Star, which is reasonable, since center and periphery are less distinctly differentiated positions in Diablo than in Star. The curve for the peripheral subjects shows a greater rise on trial 6 than does the curve for Circle-Pinwheel, and it drops nearly parallel to the latter curve until trial 10, after which it shows a gentle rise to an apparently constant value. To make a comparison to the ideal time per message, we must, in Diablo, select one of the possible optimal organizations. There are four, two of which are Star-like in that the center node does most of the message sending, and two of which are characteristically Diablo. For the peripheral nodes the latter two have the same ideal value of 2.67, and we see that the behavior comes close to that value. This does not mean that the pattern of message sending has approached the optimal, but it does mean that the sending frequency needed for the optimal pattern is met. As we shall see in the next paragraph, the same remark applies to the behavior of the center subjects in Diablo, and together these form an a posteriori justification for the time interval of 15 seconds.

The curve for Diablo center subjects during the conditioning trials starts from the trend line of the preceding trials and shows a diminishing drop almost to the ideal value of 2.00 (using the same organization that was used above to compute the ideal). The difference between the extrapolated trend line and the Circle-Pinwheel curve represents the effect of interruption and interpolated activity without, at least in the case of Pinwheel, any change of network. Let us, then, use this difference as a correction to apply to the Diablo curves. These results are shown in Fig. II.8. The effect on the center curve is to make it a straight line, while the peripheral curve still shows an initial downward trend followed by a rise to slightly above the ideal value. From these remarks, we may conclude that the change from Pinwheel to Diablo results in a message sending rate which is, in an average sense, appropriate for both center and periphery.

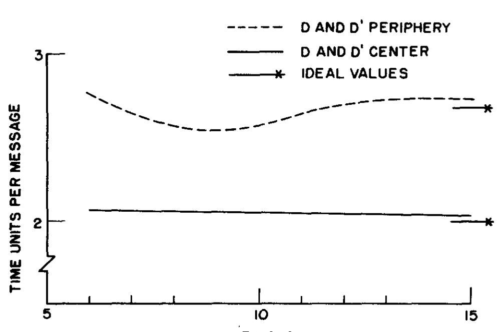

Fig. II.8

Corrected time per message for Diablo and Diablo prime.

The time per message records for the Diablo test trials are shown in Figs. II.9 and II.10 with the C-P curve common to both. We note the following facts about these data. (a) Each curve for men now in peripheral positions, except for the previous center of D', lies uniformly above every curve for men now in a center position. (b) The curve for centers of D-D' falls below those from other histories, which seems plausible, since they have had more experience in the Diablo network (before the data was combined it was noted

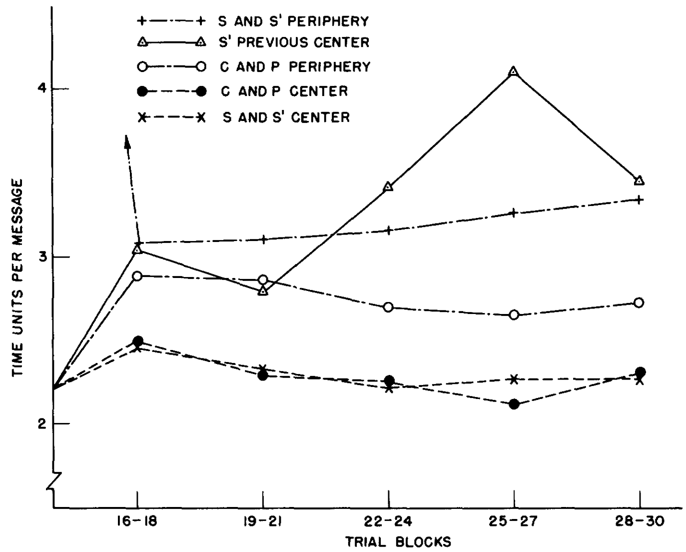

Fig. II.9
Time per message by position (test phase).

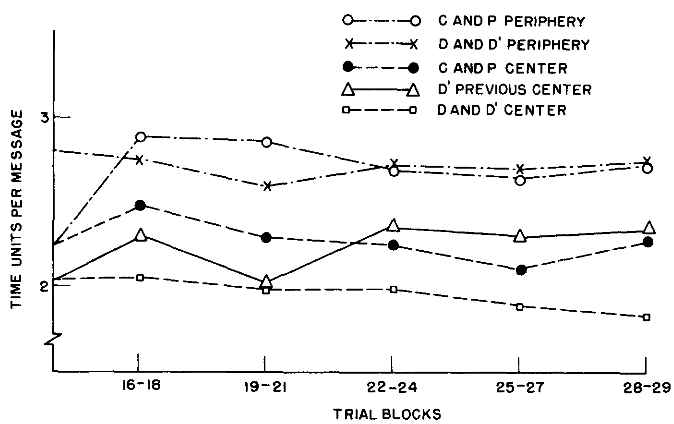

Fig. II.10
Time per message by position (test phase).

that the D data fell below that of D' at each point except the last, but the difference is small). (c) The curves for peripheral men in S-S' (except previous center) lie above those for peripheral men from other networks, the difference increasing over trials. This third fact suggests that as a result of their experience in Star these subjects are behaving in a way appropriate to Star, which is in agreement with the fact that the ideal value is, for that case, 3.20. (d) The behavior of the previous centers in S' differs from that of previous centers in D' and from all other configurations.

The last point will be examined more fully. It appears that the S' curve is nearly a magnification of the D' curve. Since the centers in Star have had a much more dominating role than the centers of Diablo, a change to a peripheral position is a more radical shift in Star. Thus, the previous centers of S' should be more keenly aware of their displacement and, in reaction, might be expected to shift to an extreme peripheral role. In fact, they do show a more extreme behavior with respect to message sending rate than do subjects from previous peripheral positions in Star. The previous centers from D', on the other hand, have a record similar to that of center men in the test phase, which indicates that they do not fully realize, at least for some time, that they have been displaced from their central role. Whether or not this hypothesis is the true explanation, it is clear from a comparison of these two position histories that the character of the previous network position can have a marked effect on behavior, in spite of current equality of position.

4. THE INFLUENCE OF PREVIOUS POSITION ON NUMBER OF MESSAGES

In section II. 2 we examined the number of messages sent in the different networks without considering the effect of position in the network, or of previous position. Since we have seen interesting differences in time per message resulting from a subject's experience in the conditioning phase, we shall examine the number of messages sent for evidence of similar effects. A suitable measure of position differences is the relative number of messages sent by center men, peripheral men, and previous center men now in a peripheral position, as expressed by the ratios

$$\frac{\text{Messages sent by center}}{\text{Messages sent by periphery}}, \quad \frac{\text{Messages sent by previous center}}{\text{Messages sent by center}}, \quad \text{etc.}$$

In plotting these quantities against the ideal ratios (discussed below), we found it desirable to introduce a transformation so that the scatter diagram would be approximately linear, and the strength of the relation would be well expressed by a correlation coefficient. Consequently, we defined index ratios as follows:

$$R_c = \frac{1}{1 + (N_p/N_c)} \qquad R_p = \frac{1}{1 + (N_c/N_p)}$$

$$R_{pc} = \frac{1}{1 + (N_c/N_{pc})}$$

where N_c is the number of messages sent by center in a trial, N_{pc} is the number sent by previous center in a trial, and N_p is the average number sent by peripheral men, averaged over all peripheral men in the group for that trial.

Using the technique mentioned in section II.2 for determining the conditional minimum number of messages for a network, we may calculate the values that the ratios given above would have if this conditional minimum pattern of message sending were followed. The ratios so calculated are referred to as ideal ratios. In Table II.1 we present the correlations taken over configurations and positions between ideal behavior and actual behavior in the test phase and between actual behavior and behavior in trial 15 of the conditioning phase. The high positive correlation between the actual and ideal behavior and the low negative between present and previous behavior show that the actual number of messages sent is determined almost wholly by the subjects' present position. When the mechanism of choice for sending messages is discussed in the next chapter the reason for this will become somewhat clearer. It is interesting to find that all of the correlations with previous behavior are negative, which is in agreement with the correlation of -0.025 between previous actual behavior on trial 15 and ideal behavior for the test phase.

5. ERRORS

The frequency of errors in the information processed by the groups was very low. This was a desirable outcome, for the study of errors was not part of the design of the experiment and their occurrence has been ignored throughout this report (except for this section). Nevertheless, there is some patterning of error frequency that supports the interpretations previously presented in this chapter and illuminates some other features of the group performance. Because of the low error rate, rather gross lumping of the data is necessary in order to gain sufficient stability to show clear trends. We have found that by some lumping of histories and by using trial blocks of length 5 we obtain satisfactory results.

There are three ways in which errors can be tabulated in this experiment. The subjects had answer sheets on which they recorded what they believed were the inputs received by the other subjects. The errors appearing on the answer sheets (final errors) are counted for the first measure. The number of messages that contain incorrect information is a second measure of errors. Erroneous messages can arise in two ways: either the man who wrote the message has made the error, or he has correctly retransmitted an item of information that came to him in error. The third measure is the number of actually committed errors. The third is probably the most basic measure, but because of the way the experimental data was coded for I.B.M. tabulation only the second measure could be obtained by machine tabulation. Since results defined by the first measure were easily obtained from the answer sheets, they were calculated for all trials. Results obtained by the second definition are tabulated for trials 15-30 only (the only trials for which I.B.M. coding was done).

The final errors are presented in Fig. II.11. We see that in the second phase Circle-Pinwheel and Diablo have about the same frequency, but the Star groups show a considerably lower error rate. This finding supports the belief that the Star groups were best organized. For the three trial blocks into which the test phase is divided we found that the differences between S and D or between S' and D' were considerably less than the differences between the primed and the unprimed configurations. Accordingly, the data is grouped C-P, S-D, and S'-D'. For each grouping there is improvement with trials, but C-P shows the highest error rate in each trial block; the primed configurations are next; and S-D is the lowest. We may conclude from this that a change of center man has a persistent effect on error rate, and that the new center man seems to be largely responsible for the increase.

Turning to the second measure, we have plotted (Fig. II.12) the error rate for the test phase with center and periphery distinguished but without regard for previous history. The records of the Army and Navy centers are plotted separately, but peripheral subjects have not been distinguished as Army and Navy, since the two records are nearly identical. The data are plotted in overlapping trial blocks in order to eliminate a moderately strong oscillation that is otherwise found superimposed on the trend line. It is first apparent that there are more errors in the messages sent by center men than in those sent by peripheral men. This can reasonably be explained as a result of the greater work load and the more rapid performance of the center subjects. If this explanation is correct, the Navy center men adapt to the pressure and reduce their error rate to a value approaching the rate of the peripheral subjects; the Army center men do not.* We are not certain of the validity of this interpretation since we are dealing with both committed errors and transmitted errors, and, since the information from one side of Diablo can only get to the other side by passing through the center, errors committed on one side are likely to appear in the messages from that side and in the center man's messages, but not in the messages sent by the opposite side. Thus, the center men may have a high error rate in terms of transmitted errors yet have no higher rate of committed errors than the peripheral subjects have. However, the improvement shown by the Navy center subjects suggests that this is not the whole explanation, for they could not reach the same level in error rate as the peripheral men and also make more transmission errors unless they had a compensatory lower rate of committed errors. This seems unlikely.

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*This statement does not necessarily apply to Army and Navy enlisted personnel generally. Our Navy subjects were mostly returned Reservists, whereas the Army personnel were mostly new inductees, hence there was an age difference and a rank difference confounded with the difference in branch of service, which may account for the difference in observed behavior.

Table II.1

Correlation of Relative Message Frequencies with Previous Behavior and Ideal Behavior (Test Phase).

Trials	Correlation with Previous Behavior	Correlation with Ideal Behavior
16-18	-0.063	0.930
19-21	-0.034	0.925
22-24	-0.079	0.960
25-27	-0.189	0.951
28-30	-0.085	0.949

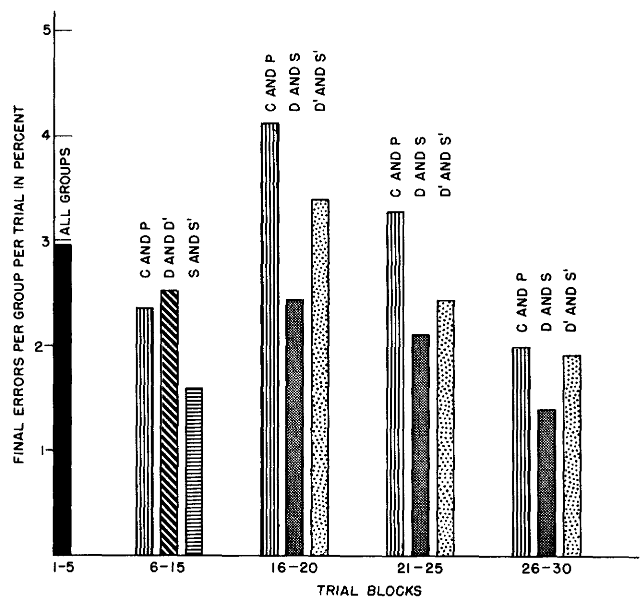

Fig. II.11
Error percentages by configuration classes.

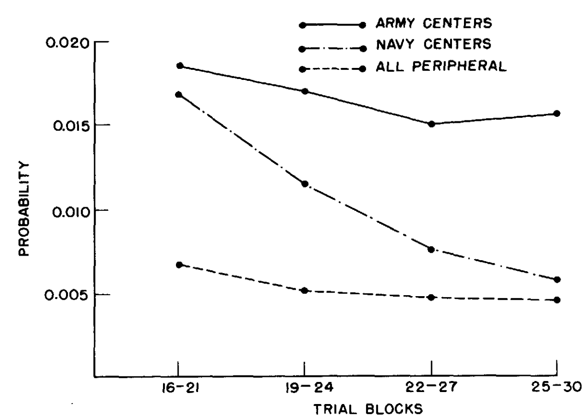

Fig. II.12
Probabilities that central and peripheral messages contain errors.

6. CONTENT OF NONPROBLEM MESSAGES

The nonproblem content of the messages sent in the test phase has been divided into the ten categories listed in section I. 5. It should be recalled that in this classification we considered each distinct statement separately, and therefore one message card may contain content in several categories. The first result we shall examine is given in Table II. 2, where we have shown the occurrence of nonproblem statements as a proportion of the number of messages sent. After the first trial block, the ratio remains substantially constant, but the constant differs radically for the center and for the peripheral subjects: approximately 0. 095 in the former and approximately 0. 22 in the latter. This, undoubtedly, is a product of the differing work loads of the two classes of subjects.

Were the frequencies adequate, we would like to display the content data simultaneously by network configuration, trial blocks, and content categories. Since this is impossible we shall treat these parameters in pairs. First, we shall consider trials and network configurations, ignoring the different content categories. The data for the center subjects are shown in Table II. 3. Since all of the configurations were substantially the same, except for the center of the S case, the table is designed to demonstrate that difference. The principal features of these data are:

A. The frequency of nonproblem messages decreases with trials so that the terminal value is approximately 50 percent of the initial value. From Table II. 2 we know this to be, in part, (and in total after the first trial block) a reflection of the over-all decrease in messages.

B. With the exception of the first trial block of S', where the frequency is 5. 1, the configurations other than S have a frequency of about 28 percent of the S value, and this does not appear to have a trend with trials.

For the peripheral subjects the picture is not as simple. First of all, in S' and D' we have two kinds of peripheral men: those who were peripheral in the conditioning phase and those who were central. The results for all of the configurations, but excluding the previous centers of S' and D', are given in Table II.4. The following points seem the most notable:

A. The frequencies in all cases are comparable to those found in S center and not with the other center positions. For the configurations other than S the ratio of the number of nonproblem messages sent by the center to the number sent by a peripheral man is 0. 41; for the S case it is 1. 63.

B. The flattest slopes with trials are shown by C, D, and D'; the steepest by S'.

C. The lowest initial value is found in D, the groups in which no change occurs between the conditioning and test phases of the experiment.

For the previous centers in S' and D' we present in Table II. 5 the ratio of their frequency of nonproblem content to that of the other peripheral men in the corresponding network. We see that (a) the ratio is substantially constant with trials; (b) this constant value is different in the two cases, and it appears that the more radical change of role

Table II. 2

Ratio of Number of Nonproblem Content Items to Total Number of Message Cards Sent During Test Phase

Node Type	Trial Blocks 1	2	3	4	5
Center	0.163	0.099	0.092	0.092	0.097
Periphery	0.341	0.262	0.235	0.201	0.210

Table II. 3

Center Node. Frequency of Nonproblem Messages Per Trial Block and Per Man for S Configuration, and Frequency for Other Configurations Combined as a Percentage of S Value

Network Configuration	Trial Block 1	2	3	4	5
S	5.3	3.4	3.3	2.8	2.8
Others in Percentage of S Value*	25.9	30.0	26.1	31.4	32.9

*Excluding S' in trial block 1 for which value is 96.2 percent of the S value.

Table II. 4

Peripheral Nodes. Frequency of Nonproblem Messages Per Trial Block and Per Man, Excluding the Previous Center Positions in S' and D'

Network Configuration	Trial Block 1	2	3	4	5
C	4.73	3.58	3.10	2.70	3.10
S	3.75	1.90	1.95	1.43	1.78
S'	5.13	2.07	1.67	1.20	0.57
D	3.03	2.28	2.23	1.58	1.53
D'	3.90	3.70	2.43	2.23	2.23
P	4.25	3.20	2.55	2.05	2.23

results in a larger frequency of nonproblem messages.

Next, we ignore the change in behavior over trials and consider the nature of the content of the nonproblem messages. In doing this we shall deal with the percent of messages in different categories, and when we lump several network configurations the percentage reported is the mean of the several percentages.

Except for the configurations S and S', the majority of nonproblem messages fall in the category "problem information asked." The figures are shown in the first column of Table II.6. The remaining columns of Table II.6 indicate the compensating changes in these distributions. The last column (Residual) includes everything not in the other columns: such items as irrelevancies about the weather and the like. A final interesting difference is shown in Table II.7, where we see that both S and P have a considerably larger level of aggression toward the receiver of the message than do the other configurations.

In the final pairwise comparison we eliminate the configurations and compare the content of messages over trials. For each trial block we present the percentage of nonproblem messages in each of the categories. These results are given in Table II.8 for the center men; in Table II.9 for the periphery. The principal features of these data are:

A. "Problem information asked" is in all cases the dominant nonproblem information, and it increases percentagewise with trials. The level is somewhat higher for the peripheral subjects.

B. The only other category that appears to increase with trials is "aggression toward the receiver." For periphery there is an approximately constant frequency of aggressive messages coupled with an over-all decrease in the frequency of nonproblem messages; for center there is a real increase of aggression.

C. As would be expected, the two "network information" categories decrease sharply with trials.

D. The category "directions sent" is initially larger in the center case than in the peripheral case, and in the former it remains nearly constant with trials, as compared with a decrease for the peripheral subjects.

We may summarize these results in a reasonably simple way. The S centers used three times as many nonproblem messages as any of the other center men (Table II.3). This probably indicates an effort on their part to reorganize and to preserve control of the group following the change from a rigid imposed organization to a more flexible one. For all other groups, either the present central man had no such experience (the case in C, P, D', and S') or he was not faced with any change (the case in D).

The peripheral men who were either previously peripheral or previously in a noncentralized network show reasonably uniform behavior (Table II.4). This uniformity depends upon the condition that these men were not in a central position during the conditioning trials for, in contrast, we see that the previous center men have a frequency of nonproblem messages appreciably exceeding the frequencies for the other peripheral

Table II.5

Peripheral Nodes. Ratio of Number of Nonproblem Messages from Previous Center Nodes to Number of Nonproblem Messages from Previous Peripheral Nodes

Network Configuration	Trial Block 1	2	3	4	5
S'	1.90	1.79	2.22	1.77	2.09
D'	1.41	1.41	1.56	1.47	1.47

Table II.6

Percentage of Nonproblem Messages in the Indicated Categories

		Nonproblem Message Category				
	Node Type	Problem Information Asked	Network Information Sent	Network Information Asked	Directions Sent	Residual
S	Center	17.6	10.8	19.9	30.7	21.0
	Periphery	33.3	15.2	6.2	7.4	37.9
S'	Center	28.4	27.2	3.7	30.9	9.8
	Periphery	43.3	16.9	10.9	16.1	12.8
Others	Center	61.7	11.5	1.8	9.3	15.7
	Periphery	76.8	5.2	2.4	6.7	8.9

Table II.7

Percentage of Nonproblem Messages in the Category "Aggression Toward Receiver"

	Node Type	Aggression Toward Receiver
S	Center	8.0
	Periphery	9.7
P	Center	9.1
	Periphery	6.8
Others	Center	1.3
	Periphery	1.7

Table II. 8

Center Node. Percentage of Nonproblem Messages in the Indicated Categories vs Trial Blocks

Nonproblem Message Category	Trial Block				
	1	2	3	4	5
Problem Information Asked	27.0	50.6	32.9	43.8	60.8
Network Information Sent	25.2	9.4	11.8	9.6	0.0
Network Information Asked	15.1	9.4	9.2	2.7	1.4
Directions Sent	22.0	20.0	22.4	21.9	16.2
Aggression Toward Receiver	0.6	2.4	6.6	8.2	9.5
Residual	10.1	8.2	17.1	13.7	12.2

Table II. 9

Peripheral Nodes. Percentage of Nonproblem Messages in the Indicated Categories vs Trial Blocks

Nonproblem Message Category	Trial Block				
	1	2	3	4	5
Problem Information Asked	58.8	72.7	65.7	70.0	71.1
Network Information Sent	15.7	6.3	6.1	3.9	2.1
Network Information Asked	5.5	4.1	4.7	3.6	1.7
Directions Sent	10.2	7.4	9.3	5.4	3.4
Aggression Toward Receiver	2.4	3.0	5.1	3.6	5.1
Residual	7.5	6.4	9.1	13.5	16.7

men in the same network (Table II. 5). The relatively large number of nonproblem messages sent by the previous center men is probably a result of their attempts to evaluate the new situation and to exercise control even though they are no longer in the naturally controlling position. We observe that this effect is more marked for the men who were centers in the more rigid conditioning organization.

With respect to content of messages the primary finding (Table II. 6) is that requests for problem information make up the dominant part of all nonproblem messages for all configurations except S and S'. In these two configurations the percentages are half of the percentages for the other cases. The primary compensation for this occurs in the two network information categories and in the frequency of directions sent. Apparently, conditioning on the rigid organization of Star results in the creation of leaders in the central position who, in the freer situation, attempt first to find out what the new situation is (see below) and then to control the other subjects.

Presumably the S' peripheral category is also high on these two counts because of the previous center man continuing to assert his control.

The other principal feature of the distribution of content is the much higher level of aggression toward the receiver of a message in S and P than in the other configurations (Table II. 7). This is consistent with the questionnaire results and with previous results (1), showing that the peripheral positions in Star and all positions in Pinwheel are comparatively less enjoyable than a central position or one in Circle. By the same argument we should expect to find the S' groups with a high count of aggressive messages except to the extent that the new situation counteracted their aggression. That we do not find a high count suggests that the "demotion" of the previous center and the added links for the peripheral subjects reduced the latter's need to express aggression.

The data of Tables II. 8 and II. 9 seem plausible from ordinary experience. One may say that content concerned with understanding the new organization decreases over time and that detailed specific problem requests increase with time.

Chapter III. INDIVIDUAL MESSAGE DESTINATIONS

1. INTRODUCTION

One of the principal goals of this study is a better understanding of the rules governing the message flow in a communication network. This is a continuation of the direction set in Technical Report No. 231 (ref. 1) where considerable effort was expended on the problem in the action-quantized case. The problem there was reasonably simple because of the enforced independence of times to reach decisions and the decisions themselves. In the present experiment they are not independent, and one might expect a very different approach would be needed; but we shall be able to follow in broad outline the same path and to use some of the same devices and assumptions that we used before, with results that can be said to be generalizations of the earlier ones.

Briefly, we shall deal with decisions and times for decisions separately, for it appears that neither is directly dependent on the other. The controlling factor, which appears to establish the indirect relation between them, is the information known to a person at the time of his choice. The decision picture, in turn, falls into two distinct parts: the initial decision an individual makes in a trial, and all subsequent decisions in the trial. The same dichotomy was found in the action-quantized case, and it was shown that the first-message behavior on one trial depended primarily on the first-message behavior of the previous trial, whereas the nonfirst-message behavior depended on the past behavior within a trial. We shall find a similar difference in the present experiment, but with some variation in detail.

This chapter is devoted to an examination of the decision behavior and the next chapter to the time behavior. With respect to decisions, we shall show that the first-message behavior of the peripheral subjects is governed by a strong perseveration from trial to trial, but that two distinct perseveration probabilities must be considered and that the resulting behavior is critically dependent on which is the larger. For nonfirst messages the behavior appears to depend very markedly on the logical difference between what information a man has and what he "knows" his receivers have.

2. PERIPHERAL FIRST MESSAGES

In a problem allowing freedom of message content there is difficulty in separating effects of problem content and those of nonproblem content. When discussing problem content the easiest way to eliminate a large part of the effect of nonproblem content is to consider only those messages that have no nonproblem content. Since about 90 percent of the first messages had no nonproblem content, we shall adopt this course in our discussion.

The most efficient communication organization in the network Diablo is for each of the peripheral subjects to send his first message to the center. The degree to which this happens can be seen in the dashed curves of Figs. III.1, III.2, and III.3. For each of the configurations the curve begins near 0.5, the equiprobable random value, and

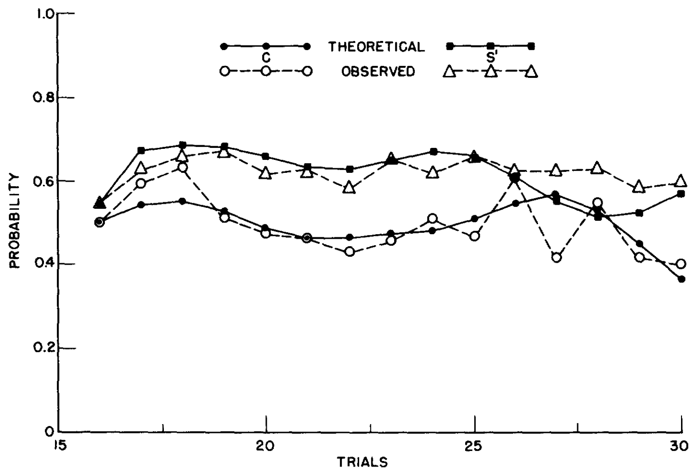

Fig. III. 1
Probability that first message is sent to center.

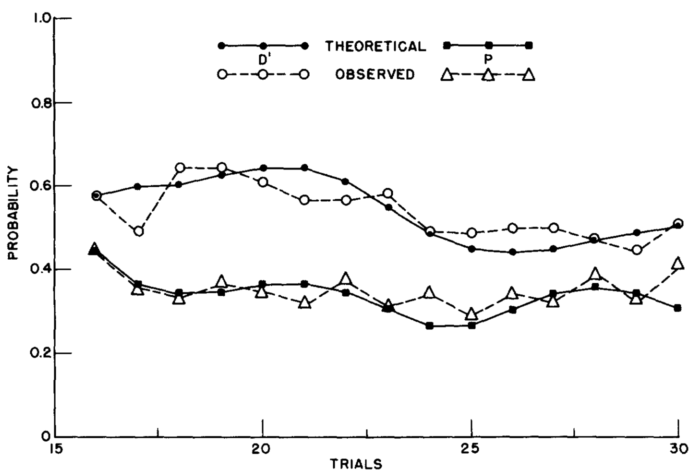

Fig. III. 2
Probability that first message is sent to center.

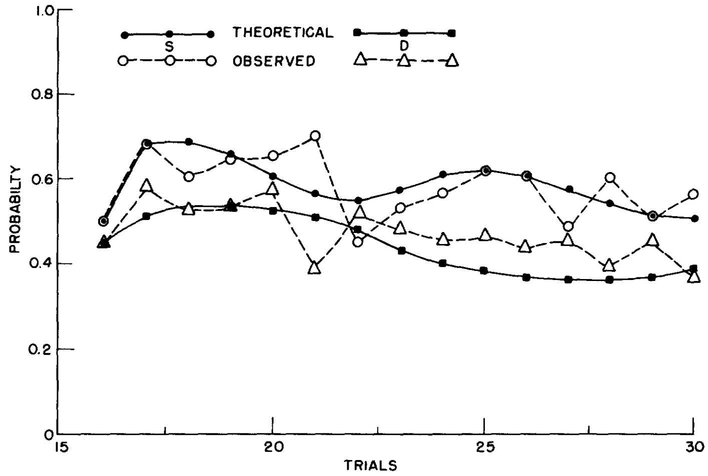

Fig. III. 3
Probability that first message is sent to center.

though there are certainly differences from this value none of the networks approaches the "rational" value of 1.0, and some have values a good deal less than 0.5. Since it would be difficult to conclude that this "globally rational" element is guiding their behavior another explanation must be sought.

In the action-quantized experiment we discovered a considerable contingency between a person's first-message destination on one trial and on the preceding trial. The selection on the first trial was equiprobable random and the subjects learned to perseverate. The learning depended on the outcome of a trial, and for that experiment an increase in perseveration tended on the average to improve the quality of group performance as measured by acts to complete a trial. One might suppose that we would also find here a perseveration of initial choices over trials. Our first attempt was to compute again a single perseveration probability, but this did not explain the observed behavior. Subsequently, the reason will be made clear. This led us to define $P_i(C)$ to be the probability of perseveration of first-message choice from trial i to trial i+1 when the choice on trial i was to the center. Similarly, $P_i(P)$ is the same quantity when the choice on trial i was to the adjoining peripheral subject. The plots of these quantities for the several configurations are shown in Figs. III. 4 and III. 5. To avoid excessively low frequencies it was necessary to compute mean values for blocks of three trials*; these are shown as points. In order to carry out a computation discussed below it is necessary to have estimates of the perseveration probabilities for each trial, hence we have introduced (non-unique) faired curves which have the property that the mean of the several

*In this and the following chapter we shall use the words "trial blocks" to refer to a grouping of the test phase into five blocks of three trials each, which will be numbered one through five.

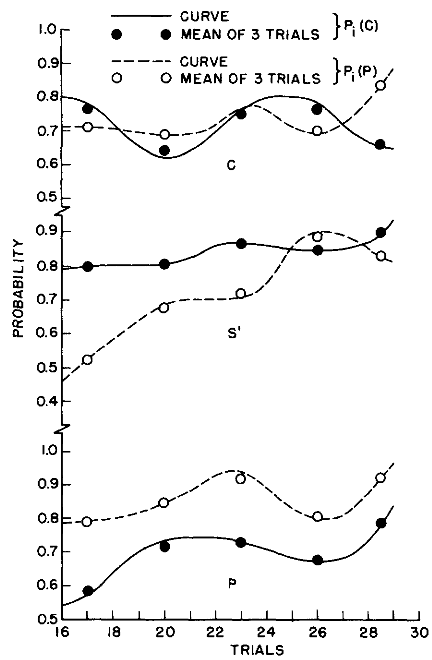

Fig. III.4
Peripheral first-message trial-to-trial perseveration probabilities.

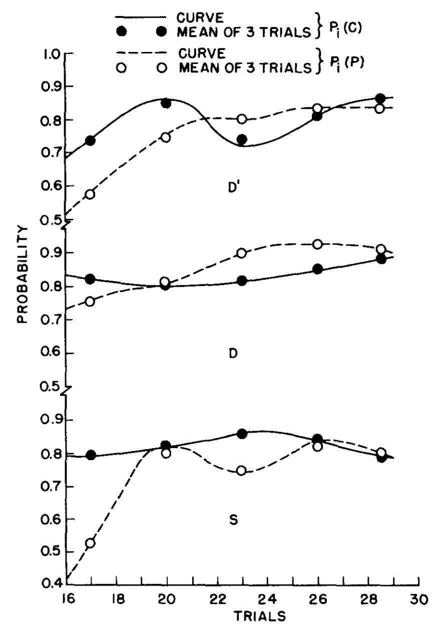

Fig. III.5
Peripheral first-message trial-to-trial perseveration probabilities.

trials in a trial block is equal to the observed value for that trial block.*

We shall not discuss these curves immediately except to note that the conjectured perseveration does exist with values in the last trial block in the neighborhood of 0.8, well above the no-perseveration value of 0.5. We must first see whether or not from such simple assumptions we can reconstruct, approximately, the curves for the probability of sending to center. If so, we may consider these curves fully accounted for by the perseveration probabilities and devote our further attention only to the perseveration.

If we let Q_i be the probability that on trial i the first message of a peripheral subject goes to the center and perseveration from trial to trial is the only mechanism in operation, then it is clear that we have

$$Q_{i+1} = P_i(C)Q_i + \left[1 - P_i(P)\right]\left[1 - Q_i\right]$$

$$= \left[P_i(C) + P_i(P) - 1\right] Q_i + \left[1 - P_i(P)\right] \qquad (1)$$

Using this equation, the faired curves for the P_i's, and the observed initial values for Q_{16}, we obtain the theoretical curves shown in Figs. III.1, III.2, and III.3. The reproduction of the data, except for details of its variability, is sufficiently good in all

*Trial-by-trial tabulations would be preferable, but I.B.M. tabulations were available in trial blocks and they have been used to save further labor and cost.

respects that we are satisfied that trial-to-trial perseveration explains the first-message behavior.

Before discussing the perseveration curves themselves, a few mathematical remarks will make clear the roles of $P_i(C)$ and $P_i(P)$. Without an explicit assumption as to their dependence on the trial number i, it is impossible to solve Eq. 1. The simplest assumption is that they are constant, in which case we omit the subscript i, and Eq. 1 becomes

$$Q_{i+1} = \left[P(C) + P(P) - 1\right] Q_i + \left[1 - P(P)\right]$$

and so we obtain

$$Q_n = \left[P(C) + P(P) - 1\right]^n Q_o + \left[1 - P(P)\right] \sum_{i=1}^{n} \left[P(C) + P(P) - 1\right]^i$$

$$= \left[P(C) + P(P) - 1\right]^n \left[Q_o - \frac{1}{1 + \frac{1 - P(C)}{1 - P(P)}} \right] + \frac{1}{1 + \frac{1 - P(C)}{1 - P(P)}}$$

Observe that for P(C) and P(P) < 1, which is certainly true, $\left[P(C) + P(P) - 1\right]^n$ approaches 0 rapidly with increasing n, and thus for reasonably large n, say 5 or better, we obtain

$$Q_n \approx \frac{1}{1 + \frac{1 - P(C)}{1 - P(P)}}$$

From this we see that the relation of Q_n to 1/2 is determined by the relation of P(C) to P(P); in the limit as $n \to \infty$ we have

$$Q_\infty \begin{smallmatrix} < \\ = \\ > \end{smallmatrix} \frac{1}{2} \quad \text{whenever} \quad P(C) \begin{smallmatrix} < \\ = \\ > \end{smallmatrix} P(P)$$

To the extent that this assumption of constant perseveration probabilities represents the empirical case, we see that the first of these three cases agrees with the P configuration data and the last with the S data. At this point the reason that led us to two distinct perseveration probabilities becomes clearer, for when we assume one, i.e. P(P) = P(C), there is a tendency for Q_i to approach 1/2 rapidly, which was not true of the data.

The prediction of the probability of sending to center from the perseveration probabilities is an advance in the understanding of the data, but it is not a complete explanation of first-message behavior, for the perseveration probabilities display features that demand explanation. There are differences due to network histories and there is a strong suggestion of an oscillatory variation in several of them. However, the exact shape of the curves must not be taken too seriously, since they are faired to fit only five data points. In what follows, no formal explanation of the perseveration phenomena has been developed; rather, we shall present a simple discussion that makes the results seem plausible.

In Fig. III. 6 general trend lines for the perseveration probabilities are presented. The data points were obtained by lumping all cases except D; these points were shifted 10 trials to the right, since these groups had experience in Diablo during the conditioning trials. The most notable feature of the trend lines is that $P_i(P)$ rises faster and goes higher than $P_i(C)$. The change in both curves over trials is presumably a learning effect, and the fact that they both have positive slopes indicates that perseveration toward both center and periphery is rewarded, the former less than the latter if the slope is an appropriate measure of learning. This seems plausible if one notes that to receive an answer to a question or a response to a statement is undoubtedly desired by the subjects, and that the chance that a peripheral subject receives a response is roughly twice as great from the adjoining peripheral subject as from the center. In particular, the groups in the P configuration spent all 15 trials of the first and second phases in the Pinwheel network, in which no direct response is possible. This may have been a mildly frustrating experience, in which case there should be a greater emphasis on feedback response in the test trials, and therefore the tendency to perseverate to periphery should be higher in P than in other configurations. It is by far the highest, and only in the P configuration is $P_i(P) > P_i(C)$ for all i.

Having found a reasonable basis for the general trend, we still have the problem of explaining deviations from it. The D data fit the trend line fairly well, when its special history is taken into account, as can be seen in Fig. III. 6. We have already considered the character of curves for the P configuration and explained it on the same basis as

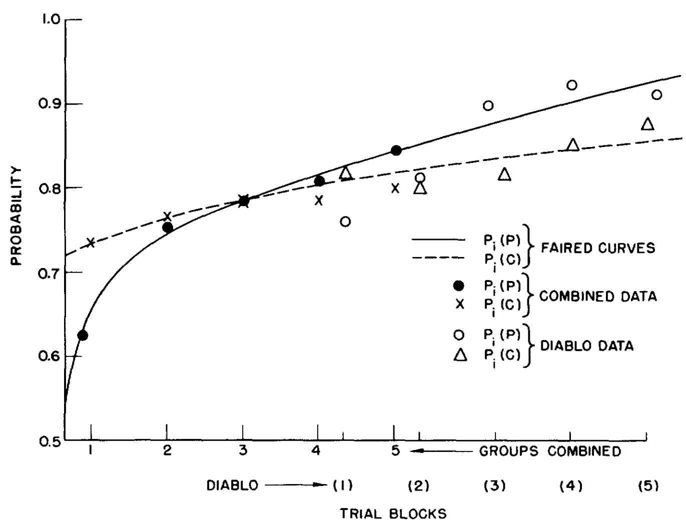

Fig. III. 6

Trend lines of peripheral first-message trial-to-trial perseveration probabilities.

the general trend. Since the change from Pinwheel to Diablo is the most radical we may suppose that there is little carry-over of perseveration tendencies and we would expect the initial values to be 0.5, approximately what they are.

Since Circle has no center and each communication channel is symmetric, the change to Diablo is not radical and whatever perseveration tendencies had developed should be carried over and should be equal initially to center and to periphery. Experience in Diablo may be expected to modify these tendencies, but because of the moderate degree of the change, so far as local connections are concerned, the modification should be slight. The figures bear this out, showing practically no trend for $P_i(C)$ and a small positive slope for $P_i(P)$.

The configurations S, S', and D' can be discussed together since they all involve important changes in the central-peripheral relations without any change in the character of the communication links. Each one has a history of experience in a centralized network, and insofar as perseveration to center depends on the characteristics of the center position a carry-over should be expected. In D' there is less initial perseveration than in the others, as would be expected from its less rigid previous centralization. With respect to $P_i(P)$, if our previous assumption was correct, its value is dependent on the responsiveness of the receiver. When the channels are changed a peripheral subject must learn by sending messages that the adjacent peripheral subject is the more responsive, so in these three configurations we should expect the $P_i(P)$ curve to be initially low and to rise rapidly as the new relations are explored and learning occurs. This phenomenon should be most severe in the S case since here all the peripheral-peripheral links are new. Such is the case.

There is a striking difference between the role of perseveration here and in the action-quantized experiment. In the latter, learning to perseverate was a vital part of improvement in performance, but in this experiment it is only perseveration to center that leads to good performance. The data indicate that, in fact, perseveration to periphery is learned even faster and it effectively negates the value of center perseveration. The conclusion from the two experiments is that there is a strong tendency for the subjects to learn to perseverate, but that this is not necessarily either beneficial or discriminating behavior.

The principal unexplained features of these data are the (possibly) cyclic phenomena. The fact that the trend lines for all groups combined were relatively smooth is evidence that any cyclic features are uncorrelated among configurations. Beyond this the data do not seem to justify further analysis, and we must leave this variation, if it exists, unexplained.

3. CENTRAL FIRST MESSAGES

For the center subjects in the network Diablo during the test phase there is nothing comparable to the probability of sending to the center, but we can again compute perseveration probabilities. It must be kept in mind that now we base our estimates on one quarter as many subjects as for the peripheral data. If we ignore past history we obtain the results shown in the last row of Table III. 1, that is, there is a perseveration probability of about 0.65, compared with the equiprobable value of 0.25. If we do not ignore past history the picture is confusing. There seem to be differences between configurations beyond purely random fluctuations. For example, the values for the S configuration are uniformly below those for S', D' is uniformly less than D, and the C and P values are somewhat interlaced.

It is the opinion of the authors that these results are, in part, artifactual, but this has not been verified. For example, it may well happen that in some groups the center subject learns to refrain from sending his first message until he has heard from one or more of the peripheral subjects. In this case we would suppose that his decisions are based on the information considerations discussed in the following two sections, and the inclusion of such cases in the calculation of the perseveration probability is inappropriate. This does not contradict the apparent center perseveration, for if we assume that the center bases his decision on information state, the observed peripheral perseveration will cause a repetition of information state that leads to center perseveration.

4. PERIPHERAL NONFIRST MESSAGES

After the first message is sent the situation changes radically. The subject is no longer concerned with the events of the previous trial, but he makes his decisions primarily in terms of what he knows has happened in the current trial. We found this behavior in the action-quantized case, and we characterized the decision in one act in terms of to whom the subject had sent and from whom he had received in the previous act. This treatment, we acknowledged, was probably only an approximation, but a rather good one, to the actual controlling mechanism, which, we felt, rested on the cumulative information previously sent and received. The approximation was justified

Table III. 1

Center First-Message Trial-to-Trial Perseveration Probabilities

Configuration	Trial Blocks				
	1	2	3	4	5
C	0.50	0.63	0.63	0.47	0.65
S	0.47	0.57	0.43	0.67	0.40
S'	0.57	0.67	0.93	0.70	0.80
D	0.87	0.77	0.73	0.73	0.85
D'	0.57	0.63	0.57	0.53	0.60
P	0.73	0.60	0.60	0.73	0.75
Average	0.62	0.65	0.65	0.64	0.68

in that case and it was used because of the ease with which the conditional probabilities could be obtained, as compared with tabulating the more exact conditions. Ironically, we were seduced by our own approximations: when the design for the analysis of this experiment was prepared (section I. 5) we carefully planned for the computations of conditional probabilities in which the conditions were described in terms of previous message destinations and sources, as in the action-quantized case. The resulting curves, which we need not present, were certainly significantly different from any number of chance models we might prepare, and therefore, according to some psychologists, intrinsically interesting; but, intuitively, the picture lacked coherence and for some curves the apparent variability was excessive. Furthermore, when we realized our errors, we examined the approximation to see if it would be as adequate here as it was in the action-quantized case, and we found the argument was much shakier.

All this is presented as background to the statement that the conditional probabilities presented in this and the following section will be for only the first, third, and last blocks of three trials from the test phase of the experiment. Since the computation could not be carried out on I.B.M. equipment without preparing a complete set of new cards, each case had to be individually examined by hand, and though the task was materially facilitated by the work that had gone into the reduction of the data for I.B.M. processing, time would not permit obtaining the complete set of five trial blocks. As we shall see, the loss of the second and fourth trial blocks is not very important.

If one assumes that the subjects have only a vague awareness of the total network structure, an assumption that from the questionnaire (section V. 1) and other observations seems reasonable, one might expect that the subjects base their decisions on some aspects of the local information flow. Our problem is to determine what these aspects are. There is one logical procedure they might follow which, for the sake of a term, we shall call the "locally rational" one. A subject can know all the information he has received during a given trial, and for each of the subjects to whom he may send he can know that they have their own information, that they have whatever he has sent them, and that they have whatever they have sent him. By taking the logical difference of what he knows and what he knows is the least that another subject has, he can determine the maximum amount that his message can add to that potential receiver. For example, suppose the pieces of input information are labelled according to who received them initially, 1, 2, 3, 4, and 5. Let us consider man 1 and suppose that he can communicate with 2 and 3, as in Fig. III. 7. Suppose that prior to the instant under consideration subject 3 has sent him 3 and 4, and that he has sent 3 his own number 1. Also, suppose he has sent 1 to subject 2, but 2 has not sent him a message. Then he has 1, 3, 4, and he knows that subject 3 has (at least) 1, 3, and 4, and that subject 2 has (at least) 1 and 2. Thus, he can conclude that a message to 3 will add no information, whereas a message to 2 may add 3 and 4. If a person actually perceived the situation this way, and if there were no other

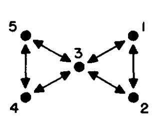

Fig. III. 7

considerations such as a question to be answered, it is reasonable to suppose that he would send his message to 2. We shall say that the locally rational behavior is to send to a subject to whom he knows he may add information, provided he knows he cannot add any information to the other subjects to whom he can communicate. What he "should" or "would" do when, from his local point of view, he has new information for several of the subjects to whom he can send, or when he has no new information for any of them, is certainly less clear.

For a peripheral subject we may characterize the conditions as new information for center, peripheral, both, or neither, for which we use the symbols C, P, B, or N. Similarly, a message may go to either C or to P, that is, to the center or to the adjoining peripheral subject. So we shall deal with $P(X|Y)$, the probability that a message is sent to X when the subject is in condition Y.

In estimating $P(X|Y)$ there is some question as to which messages to consider. Certainly not the first ones and certainly not those that contain no problem information at all. The difficult cases are those that include both problem and nonproblem information, for the destinations of some of these messages are determined by the problem situation with the nonproblem content, such as comments on performance, and the like, gratuitously included. Other messages, however, have specific requests for problem, or network information, or they instruct the receiver to do something, and it is conceivable that this content is the dominant determiner of the destination, and that the problem information is the incidental content. While this distinction poses a very subtle problem, it does not appear to matter appreciably in this experiment. First, we present in Table III.2 the values of $P(X|Y)$ for all nonfirst messages that contain any problem information. Second, in Table III.3, we present the same probabilities for nonfirst messages, excluding those with any nonproblem content. It is apparent that there is little difference between these two tables, but the close similarity may very well stem from the relatively small change (of the order of 15 percent) in total frequency between these two conditions.

The most striking features of these tables are the very high probabilities obtained for the two unequivocal cases, in the neighborhood of 0.95 or higher in the third and fifth trial blocks, and the minor differences between network histories in these two cases. One cannot conclude that the conditioning trials had an appreciable effect on $P(C|C)$ or $P(P|P)$ except that the configurations involving the greatest change, C, P, and S', start definitely lower than the others. Our subjects' behavior was remarkably close to the locally rational pattern, and the estimates of their "rationality" given in these tables are probably conservative for the following reason: there is no assurance that the subjects always take into account all the cards they are supposed to have received. It was observed in running the experiment that if a message was in preparation when a tone sounded some subjects would continue to work on it, ignoring any messages they received on that tone. Thus our data record would indicate the receipt of a card that had not been considered when the message was prepared. Apparently, this was a relatively minor effect, but if it were taken into account it might push these conditional

Table III. 2

P(X|Y) for Nonfirst Messages Containing Problem Information
(average value based on frequencies)

Configuration	P(C|C)			P(P|P)			P(C|N)			P(C|B)		
Trial Block	1	3	5	1	3	5	1	3	5	1	3	5
C	0.82	0.98	0.96	0.86	0.92	0.94	0.68	0.46	0.45	0.51	0.47	0.38
S	0.93	0.98	0.95	0.86	0.94	0.93	0.62	0.62	0.62	0.31	0.43	0.50
S'	0.80	0.99	0.98	0.90	0.94	0.97	0.57	0.56*	0.75*	0.47	0.43	0.50
D	0.95	0.95	0.95	0.90	0.91	0.90	0.56	0.61	0.45	0.62	0.64	0.61
D'	0.94	0.95	0.97	0.95	0.96	0.98	0.65	0.52	0.33*	0.50	0.45	0.19
P	0.89	0.93	0.96	0.83	0.94	0.95	0.59	0.62	0.46	0.55	0.58	0.44
Average	0.89	0.96	0.96	0.88	0.93	0.95	0.61	0.54	0.48	0.49	0.50	0.41

*Frequency less than 10.

Table III. 3

P(X|Y) for Nonfirst Messages Excluding Those with any Nonproblem Content (average value based on frequencies)

Configuration	P(C|C)			P(P|P)			P(C|N)			P(C|B)		
Trial Block	1	3	5	1	3	5	1	3	5	1	3	5
C	0.82	0.99	0.98	0.86	0.95	0.98	0.70	0.38	0.44	0.53	0.49	0.32
S	0.99	0.99	0.97	0.89	0.96	0.93	0.65	0.67	0.71*	0.35	0.43	0.44
S'	0.87	0.99	0.98	0.93	0.95	0.98	0.52	0.67*	0.75*	0.45	0.43	0.46
D	0.94	0.99	0.97	0.93	0.95	0.89	0.61	0.50	0.38	0.59	0.63	0.67
D'	0.94	0.99	0.98	0.95	0.96	0.99	0.70	0.44	0.33*	0.48	0.46	0.21
P	0.90	0.96	0.95	0.84	0.94	0.97	0.63	0.65	0.44	0.54	0.60	0.52
Average	0.91	0.98	0.97	0.90	0.95	0.96	0.63	0.50	0.46	0.49	0.50	0.41

*Frequency less than 10.

probabilities to almost 1.0. It will surely become an important effect in experiments performed in continuous time. There must come a time when a subject says, "This is my decision," and ignores all new messages. There is a counter effect, however, that tends to cause an overestimate of the probabilities: in some cases subjects sent to the rational place messages that did not include the information that he would rationally believe was missing at that place. This comment must, of course, be tempered by the remark concerning messages received and not considered.

In the "neither" category we are dealing with messages that served no problem function and that, except for those with nonproblem content, should never had been sent. Their existence may reflect the phenomenon that message sending was stimulated by the last message sent rather than by the receipt of a message (this point will be discussed in detail in chapter IV). In the last trial block, the "neither" messages with no nonproblem content comprise 5 percent of all the nonfirst messages sent. Judging by the relatively consistent pattern over network histories one may conclude that a fairly random pattern of decision was involved, beginning at about 0.6 probability of sending to center and reducing to 0.5, or a little less, in the final trial block. The mechanism of change over trials is not understood.

The "both" condition is even more troublesome. The frequency in this category is at least double that in the "neither" one, for those with no nonproblem content are 10.4 percent of all nonfirst problem messages. There appears to be much to be explained; not only is the variation over network configurations wide, with ample frequencies involved, but the variation over trials seems to lack a consistent pattern. One senses that these probabilities are not the basic facts. As in the first-message behavior, we should like to find some more basic underlying probabilities. In contrast to that problem, we have not been successful here. We shall discuss briefly some of the attempts that did not succeed.

First, one might suppose that a subject would send to the person for whom he has more information; however, in most "both" situations that arise he has equal amounts for each of the two potential receivers, usually one piece.

Second, his estimate as to which of the two people has less information might provide a basis for decision. This possibility fails to serve, for in only very few of the cases does the center have less information, and the others cases are split roughly equally between peripheral-fewer and same-for-each.

Third, it might be that a subject would prefer to send to the person whom he knows does not have his original input information. Most of the "both" cases would be included in such a tabulation, for there are only about 20 percent of the "both" cases in which he knows that both of his potential receivers have his input information. We shall not present this tabulation for it can readily be seen to be very similar to the one discussed below, which has the advantage that it is based on frequencies roughly one quarter larger.

Fourth, one might imagine that when a subject is in the "both" category there would

Table III.4

Probability of Alternation from Previous Choice for Peripheral Subjects in "Both" Condition

Configuration	Previous Message to Center			Previous Message to Periphery		
	Trial Block					
	1	3	5	1	3	5
C	0.69	0.59	0.79	0.69	0.62	0.63
S	0.83	0.75	0.56	0.58	1.00*	0.75*
S'	0.59	0.62	0.55	0.59	1.00*	1.00*
D	0.39	0.38	0.39	0.56*	0.71	0.67*
D'	0.60	0.62	0.91	0.64	0.60	0.36
P	0.56	0.53	0.58	0.74	0.73	0.50*

*Frequency less than 10.

be a tendency to alternate from the previous choice. Table III.4 presents this data under the headings "previous message to center" and "previous message to periphery." It should be observed that, in a sense, this breakdown is similar to the one that worked for first messages. Our feeling is that the analysis is still unsatisfactory, although it is a little more coherent than the original tabulation. Note that all the probabilities for previous message to center are well above 0.5 except the D values, which are less than 0.4 in all three trial blocks. For previous message to periphery the picture is less clear, but this is in part caused by the low frequencies, particularly in the last trial block. More perplexing are the apparent changes over trials, such as in "D' previous message to center" which rises from 0.6 to 0.9, and in "S previous message to center" which drops from 0.8 to 0.6.

It is hard to believe that either an alternation tendency or a preference for sending one's own input account well enough for the data to be called the basic phenomenon. One or the other may well play a role, supplemented by some undiscovered factor, or, possibly, we have simply not found the true basis for the decisions.

5. CENTRAL NONFIRST MESSAGES

Our first attempt at analysis of the nonfirst messages of the center subjects was in terms similar to those of the preceding section, but this analysis did not yield useful results. Often, by the time the center man sends his second message, and usually for all subsequent messages, he is already in possession of all the information. Consequently, in an analysis in terms of local rationality, he will have on his second message new information for all four peripheral men; on his third message, new information for three of them; and so forth. In almost every case, the observed messages were sent to one of the peripheral men for whom the center could logically expect to have new information. These results are not tabulated, since the probabilities of this form of "locally rational" behavior are all over 0.97 and they show no interesting differences between network experience.

We find ourselves with the situation that almost anything the subject does is good, for he has new information for everyone. We can argue, therefore, that it does not matter what he does and the selection of a destination is random. This, we may easily demonstrate, is false. If we consider on each trial the first message at which the center subject has all the information, and note the probability of perseveration, i.e. that the center man will send this message to the same destination from trial to trial, we obtain the results shown in Table III.5. The lowest value in this table, 0.40, is well above the chance value of 0.25, which would be obtained if the choices on two successive trials were completely independent. Again, we appear to find trial-to-trial perseveration a dominant factor in an ambiguous situation, but it is by no means certain that this particular probability is the crucial one. First, the breakdown of the data by configurations does not yield a very intelligible picture: it is hard to adduce arguments for combining C and D', S and P, and S' and D, which the data suggest. Second, when dealing with perseveration in a situation such as this we must be sure that we are not examining an artificial perseveration, for a combination of basic perseveration on the part of others and some basic locally rational decisions on the part of center certainly can lead to significant but artificial perseveration probabilities for center. In any case, the perseveration shown in Table III.5 is either basic or is an indicator of the existence of a phenomenon more interesting than equiprobable chance.

After a center man has sent one message containing all the information, there are, in general, three men left to whom he can reasonably send. His choice, almost without exception, is among these three. It is evident that the wisest choice would be send to one of the two peripheral men who cannot communicate with the one man to whom the center has already sent the answer. A random choice would yield a probability of 0.67 of sending to one of these two men; the observed probabilities are shown in Table III.6. If we assume that each value in the table is based on 30 points (which is not strictly true, since each of 10 subjects is represented three times), a value in excess of 0.92 is significant at the one-percent level. This occurs only in S' in the last trial block. However, 16 of the 18 values are equal to or greater than the chance value, and 13 are strictly greater, which suggests that something more than a chance mechanism is operating. If there is any learning – which is not certain – it is not surprising that it is slight, since it is relatively unrewarded. The only difference it is liable to make is 1 time unit out of 8 to 12 units and, furthermore, there is a moderately high probability of making the correct choice purely by chance.

After the first two messages that contain all of the information, it is effectively

Table III.5

Center Subjects. Trial-to-Trial Perseveration Probabilities for the First Message after the Center Has All the Problem Information

Configuration	Trial Blocks		
	1	3	5
C	0.53	0.40	0.45
S	0.53	0.47	0.65
S'	0.47	0.93	0.90
D	0.60	0.83	0.90
D'	0.40	0.43	0.45
P	0.57	0.67	0.75

Table III.6

Center Subjects. Probability that the Second Message after the Center Has All the Problem Information is to One of the Peripheral Subjects not Connected Directly to the Subject Who Received the First Message Containing All Information

Configuration	Trial Blocks		
	1	3	5
C	0.67	0.67	0.83
S	0.87	0.77	0.74
S'	0.63	0.90	0.93
D	0.73	0.83	0.70
D'	0.77	0.70	0.63
P	0.74	0.72	0.67

immaterial which choice is made between the remaining two men; the time per trial is, in general, now determined to within one time unit.

In summary then, the center men, like the peripheral men, send messages to one of the subjects for whom they know they may have new information. If there are several such, as there almost always are when the center has first obtained all the information, the mechanism is not clear. Certainly, there is a strong perseveration from trial to trial, but we are not yet convinced that our measure is not the composite of some other more basic factors. After this first choice, if the center is conscious of the network in detail, he should send to one of the two subjects who cannot communicate directly with the one to whom the center first sent the total information. The tendency to do this, if there is any, is certainly slight. This is in agreement with the results of section V.1, where it will be seen that knowledge of indirect links in the network is also slight.

6. SUMMARY

The first main point of this chapter was the necessity of dividing the messages sent into two classes: first messages and nonfirst. In truth, the classification is not really that, but rather messages sent before any message has been received and those after a receipt. In this experiment the two classifications are very nearly the same. For the former category we found that behavior was governed by the behavior on previous trials. By the very definition of that class there were no current stimuli that could dictate the message destination, and the subjects relied strongly on their behavior in the previous trials, ultimately showing perseveration probabilities in the neighborhood of 0.8. In contrast to our previous work, this study indicates that it is necessary to consider different perseveration probabilities when there is a strong difference in the network position of the receivers. In the case of the network Diablo the perseveration tendencies do not have the "globally rational" property of causing the first message to be sent to the center man; in fact, the probability ranged only from 0.4 to 0.6, the value depending on the previous experience of the group. The effect of previous experience is not at all clearly understood; the explanation we gave was merely qualitative and it is to be expected that within broad limits of possible results we could have developed a plausible verbal discussion.

With respect to later messages in the trial the picture seems to fall into three categories. If one computes the logical difference of what one man has and what he "knows" that each of the men to whom he can send has, either all of these sets are empty, only one is nonempty, or several are nonempty. For the middle case, the behavior is clear: with probabilities exceeding 0.95 the subject sends to that one person for whom he may have new information. For the first and last cases the behavior is far less clear. It may very well be that the probabilities we have observed are the result of mental coin tossing, and that they are the ultimate determiners of behavior; however, the consistent differences between groups with divergent network histories suggest that we have not yet reached the heart of the matter. Of greatest interest is the behavior when several of the sets are nonempty — those called "both" in this particular experiment; for when they are all empty it is, from the point of view of information flow, immaterial what choice is made. As far as the assumptions of a model for information flow are concerned, the outstanding unsolved problem is the character of human behavior when several of the sets are nonempty. This is also likely to be a problem of greater psychological interest, since there is no obvious course of action for the subject. His choice, therefore, may be governed by more subtle, and hence more interesting, psychological factors.

Chapter IV. INDIVIDUAL TIME DATA

1. THE INDIVIDUAL TIME DISTRIBUTION

In this and in the following sections we shall discuss the latency of individual messages. From a consideration of these latencies and the decision process itself (chapter III) we may be able eventually to understand the group latencies discussed in chapter II.

It will be recalled (ref. 1, pp. 92-94) that if one assumes that an organism is stimulated at time 0, and that the probability of response in the interval $(t, t + \Delta t)$ is approximately $\lambda(t)\,\Delta t$, provided no response has occurred between 0 and t, the latency is given by

$$f(t) = \lambda(t) \exp\left[-\int_0^t \lambda(x)\,dx\right] \tag{1}$$

In the previous report (1) we found that the individual latencies were fitted adequately by taking $\lambda(t)$ to be a constant, but we pointed out that there was little reason to suppose that the rising limb was actually as sharp as the exponential function. Nothing conclusive could be determined about this, since we were forced to a procedure of analysis in which the shape of the rising limb was not critical.

In the following work we shall not make such an assumption; rather we shall deal with the function $\lambda(t)$ directly, or with its integral

$$\Lambda(t) = \int_0^t \lambda(x)\,dx$$

Equation 1 can be written

$$f(t) = \frac{d\,\Lambda(t)}{dt} \exp\left[-\Lambda(t)\right]$$

Integrating, we obtain

$$F(t) = \int_0^t f(x)\,dx = 1 - \exp\left[-\Lambda(t)\right]$$

Hence, we have

$$\Lambda(t) = -\log_e\left[1 - F(t)\right] \tag{2}$$

If we differentiate Eq. 2, we have

$$\lambda(t) = \frac{f(t)}{1 - F(t)} \tag{3}$$

We shall in fact use only Eq. 2, even though Eq. 3 represents $\lambda(t)$ directly. The reason is, of course, that Eq. 3 contains $f(t)$ on the right side, which is the derivative of $F(t)$, the observed data. It is well known that differentiation of empirical results is a very risky operation and to be avoided.

The suggestion might be made, nonetheless, to use Eq. 3 in an indirect way by computing the average value of $\lambda(t)$ over the time intervals for which the empirical data are lumped. This is worthy of consideration. First, suppose that the data are grouped between the points t_i, $i = 1, 2, \ldots, n$. Define

$$\lambda(i) = \frac{1}{(t_{i+1} - t_i)} \int_{t_i}^{t_{i+1}} \lambda(x)\, dx$$

then the step function

$$\lambda^*(t) = \begin{cases} \lambda(i) & t_i \leqslant t \leqslant t_{i+1} \\ 0 & \text{elsewhere} \end{cases}$$

is the approximation to $\lambda(t)$ which assumes its average value over the arbitrary intervals into which the data are grouped. Consider the distribution

$$f^*(t) = \lambda^*(t) \exp\left[-\int_0^t \lambda^*(x)\, dx\right]$$

Observe that

$$\int_{t_i}^{t_{i+1}} f^*(t)\, dt = \int_{t_i}^{t_{i+1}} \lambda^*(t) \exp\left[-\int_0^t \lambda^*(x)\, dx\right] dt$$

$$= \int_{t_i}^{t_{i+1}} \lambda(i) \exp\left[-\sum_{j=1}^{i-1} \lambda(j)\,(t_{j+1} - t_j) - \lambda(i)\,(t - t_i)\right] dt$$

$$= \lambda(t) \exp\left[-\sum_{j=1}^{i-1} \lambda(j)\,(t_{j+1} - t_j)\right] \int_{t_i}^{t_{i+1}} \exp\left[-\lambda(i)\,(t - t_i)\right] dt$$

$$= \exp\left[-\sum_{j=1}^{i-1} \lambda(j)\,(t_{j+1} - t_j)\right] \left[1 - \exp\left\{-\lambda(i)\,(t_{i+1} - t_i)\right\}\right]$$

also that

$$\int_{t_i}^{t_{i+1}} f(t)\, dt = F(t_{i+1}) - F(t_i) = -\exp\left[-\Lambda(t_{i+1})\right] + \exp\left[-\Lambda(t_i)\right]$$

but

$$\Lambda(t_i) = \int_0^{t_i} \lambda(t)\, dt = \sum_{j=1}^{i-1} \lambda(j)\,(t_{j+1} - t_j)$$

therefore

$$\int_{t_i}^{t_{i+1}} f(t)\, dt = \exp\left[-\sum_{j=1}^{i-1} \lambda(j)\,(t_{j+1} - t_j)\right]\left[1 - \exp\left\{-\lambda(i)\,(t_{i+1} - t_i)\right\}\right]$$

and we may conclude that

$$\int_{t_i}^{t_{i+1}} f^*(x)\, dx = \int_{t_i}^{t_{i+1}} f(x)\, dx = \text{observed data}, \quad i = 1, 2, \ldots, n$$

Thus, the average value is the unique step function constant over the intervals (t_i, t_{i+1}) which exactly reproduces the original data. From this point of view, then, it is perfectly suited to our task.

Let us evaluate $\lambda(i)$

$$\lambda(i) = \frac{1}{(t_{i+1} - t_i)}\left[\int_0^{t_{i+1}} \lambda(t)\, dt - \int_0^{t_i} \lambda(t)\, dt\right]$$

$$= \frac{1}{(t_{i+1} - t_i)}\left\{\log_e\left[1 - F(t_i)\right] - \log_e\left[1 - F(t_{i+1})\right]\right\}$$

$$= \frac{1}{(t_{i+1} - t_i)} \log_e\left[\frac{1 - F(t_i)}{1 - F(t_{i+1})}\right]$$

Thus, we can express $\lambda(i)$ in terms of the observed data alone, but as the ratio of two differences. Since these differences are small for much of the range of t, the ratio is quite unstable and the accuracy of estimation is bad. In fact, the occurrence of the ratio simply reflects the fact that the data must be differentiated, now approximately, to obtain $\lambda(i)$, an approximation to $\lambda(t)$. Thus, we conclude that the average value is little more suited for study than $\lambda(t)$ itself; therefore, in what follows we shall use only Eq. 2.

The reason for including the calculation given above is to demonstrate the caution necessary in handling empirical data of this sort. Since Eq. 2 is but a transformation of the original data, the value of using it instead of the data may be questioned. We do this for two reasons: first, the probability density $\lambda(t)$, or $\Lambda(t)$, is slightly more basic than the distribution; second, and more important, it is an empirical fact that $\Lambda(t)$ is very nearly a straight line, hence the latency distribution is very nearly an exponential; it is far simpler to note changes from a straight line, and to compare two nearly straight lines, than it is to carry out the same operations with exponential curves.

2. THE INDIVIDUAL TIME DATA

From the analysis of the action-quantized case, it was suggested that the preparation of messages and their transmission was a phenomenon triggered by the receipt of other messages, and an abortive theory based on this assumption was discussed (ref. 1, pp. 124-130). It was found that this assumption led to formidable mathematical difficulties. It is also clear that there is some relation between the time of sending of a message and the time of the immediately preceding one; some delay must occur for the preparation of the new message. Therefore, in this experiment, it was decided to examine both of these differences: the time between the present sending and the most recent receipt, and the time between the present sending and the immediately preceding sending. We shall refer to these as the R and S cases, respectively. From section I. 5 it is clear that both of these distributions can be obtained.

An examination of the data showed that for the considerations of this section no distinction need be made between Army and Navy subjects, nor did the previous experimental history of the groups produce any appreciable effect. The latter statement stands in apparent contradiction to the conclusions of section II. 3 where the time per trial divided by the number of messages per trial was discussed. The difference stems in part from the fact that a rather long time may elapse between the last sending of a peripheral subject and the end of the trial — a fact that entered the considerations of the earlier section but not of this one. The deviation of peripheral subjects who were centers in the conditioning phase must be accepted as real, but this is mitigated by the fact that only one subject in 12 is in this category and by the fact that those in D' have an effect opposite to, though not fully equal to, those in S'. The final criterion, however, in ignoring histories was the marked similarity of the distributions in the six cases. Consequently, the data have been divided into trial blocks of three trials each and presented separately for the center and peripheral subjects, for the various amounts of problem information present at the sending node, and for times since last sending and last receipt. This breakdown resulted in frequencies in the hundreds for most cases.

We shall use the following abbreviation: a three-position symbol in parentheses tells in the first entry whether the subjects were center (C) or peripheral (P), in the second the number of pieces of problem information present at the time of sending, and in the third whether we are considering the receipt (R) or send (S) condition. Thus, (P,5,R) means peripheral subjects with five pieces of problem information present (they know the answer) and the times since the last receipt are under consideration.

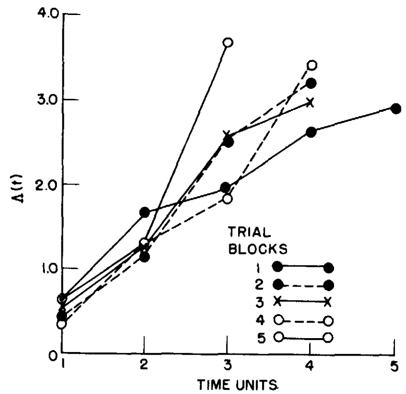

Fig. IV.1
Plot of $\Lambda(t)$ vs time units for (C, 3, S).

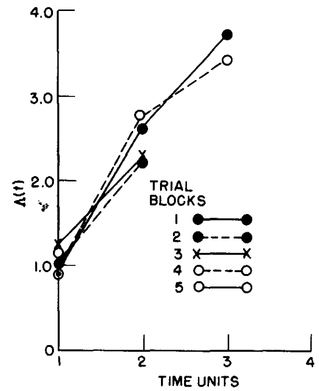

Fig. IV.2
Plot of $\Lambda(t)$ vs time units for (C, 3, R).

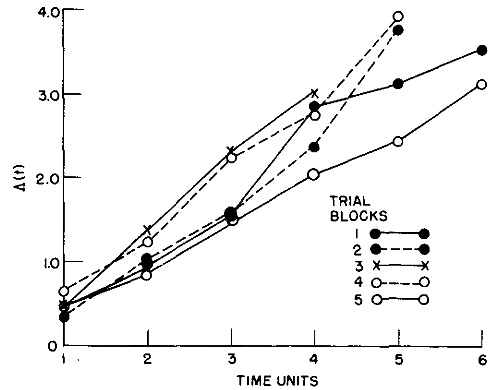

Fig. IV.3
Plot of $\Lambda(t)$ vs time units for (C, 4, S).

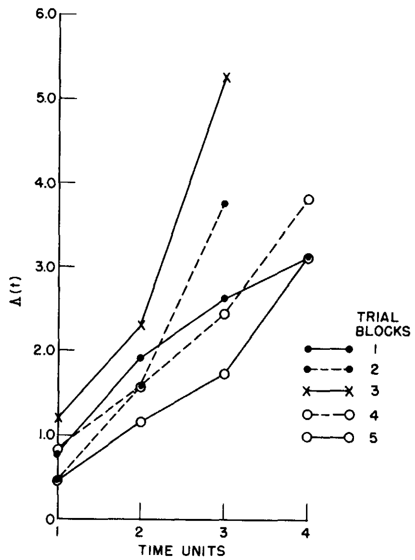

Fig. IV.4
Plot of $\Lambda(t)$ vs time units for (C, 4, R).

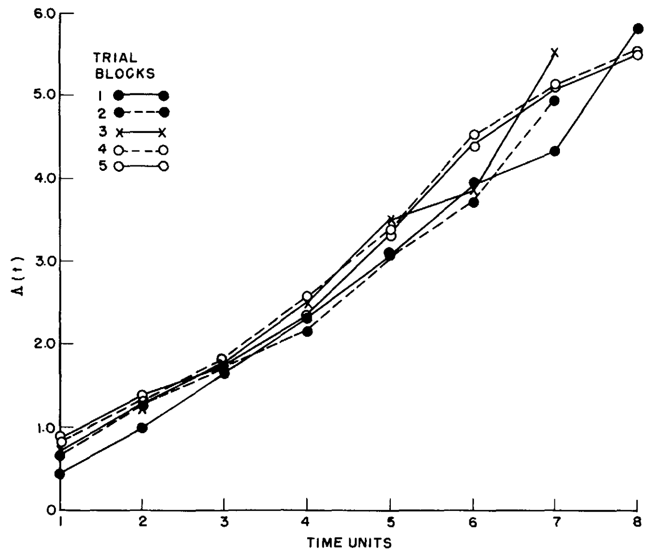

Fig. IV.5
Plot of $\Lambda(t)$ vs time units for (C, 5, S).

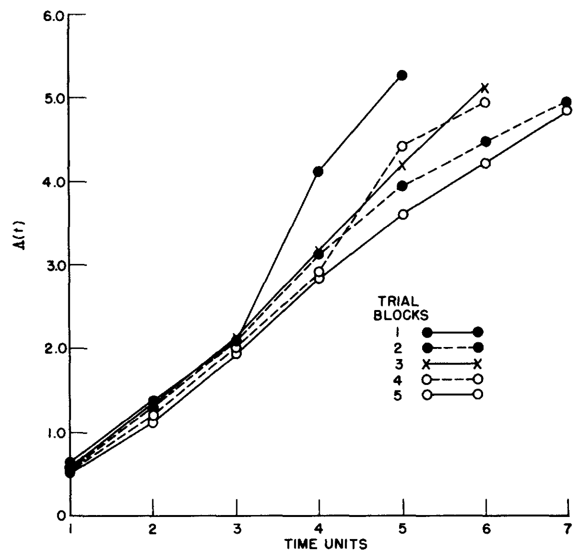

Fig. IV.6

Plot of $\Lambda(t)$ vs time units for (C, 5, R).

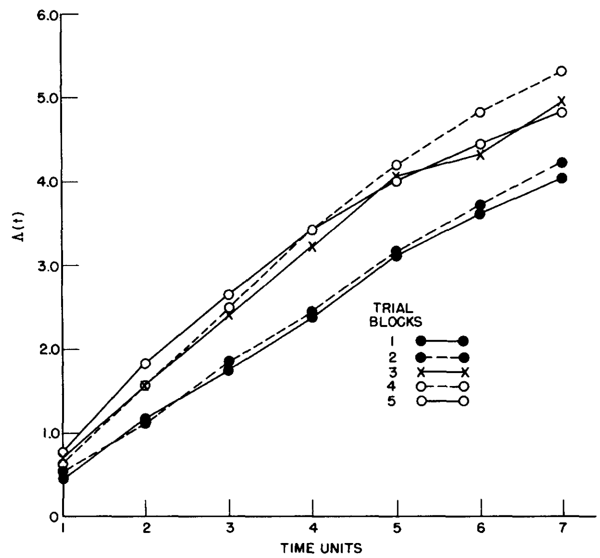

Fig. IV.7

Plot of $\Lambda(t)$ vs time units for (P, 2, S).

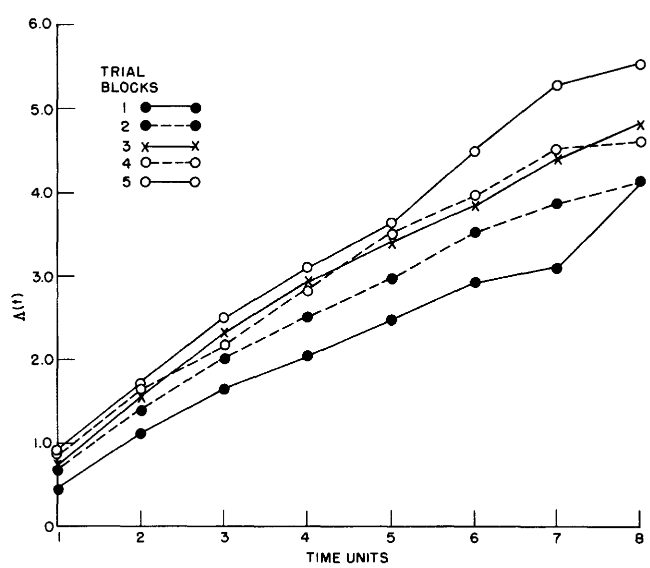

Fig. IV.8

Plot of $\Lambda(t)$ vs time units for (P, 2, R).

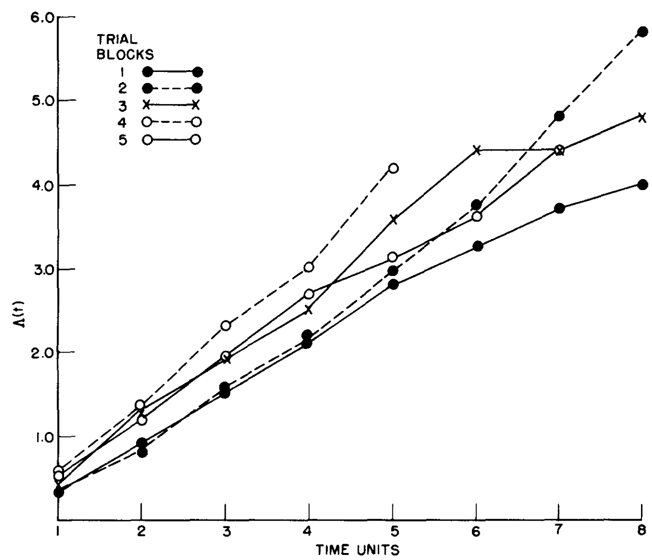

Fig. IV.9
Plot of $\Lambda(t)$ vs time units for (P, 3, S).

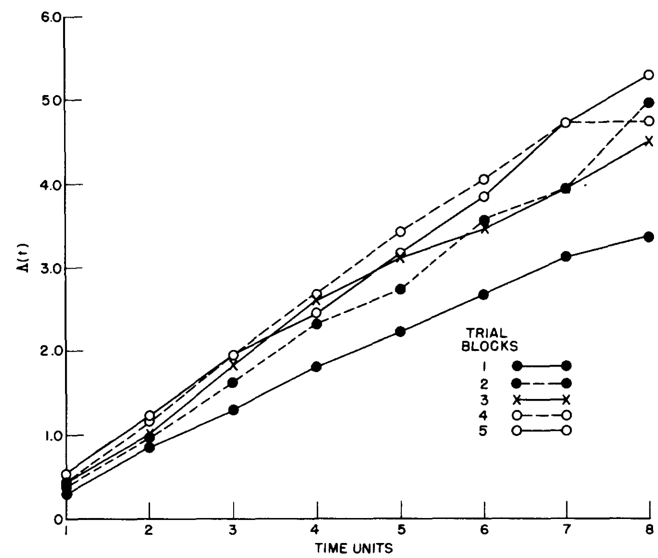

Fig. IV.10
Plot of $\Lambda(t)$ vs time units for (P, 3, R).

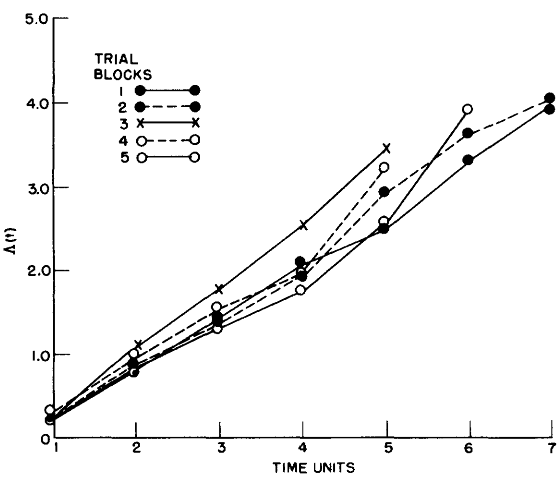

Fig. IV.11
Plot of Λ(t) vs time units for (P, 4, S).

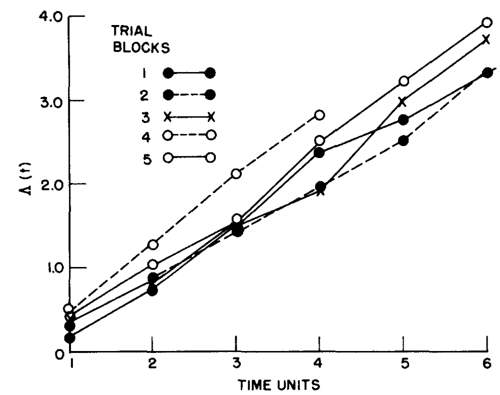

Fig. IV.12
Plot of Λ(t) vs time units for (P, 4, R).

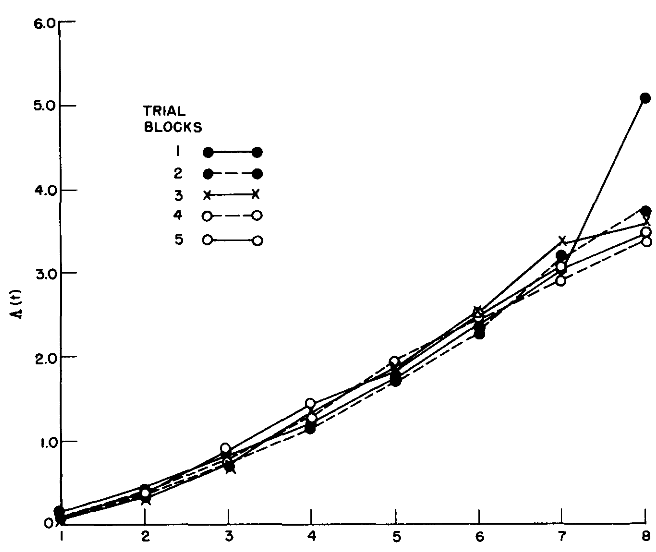

Fig. IV.13
Plot of Λ(t) vs time units for (P, 5, S).

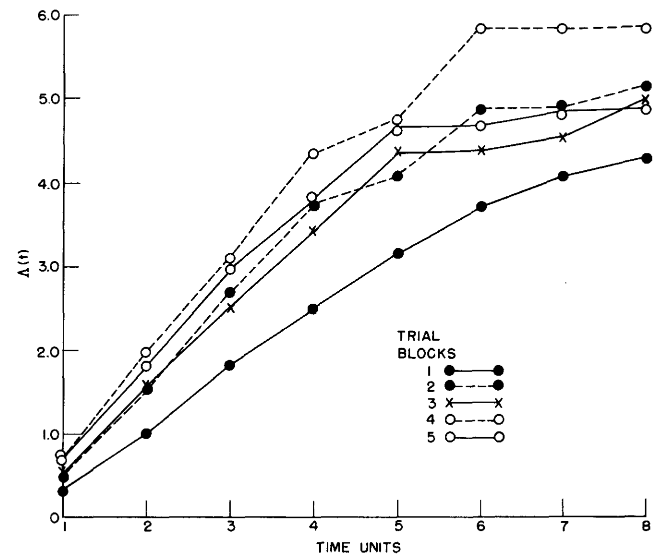

Fig. 14
Plot of $\Lambda(t)$ vs time units for (P, 5, R).

It will be recalled that the time scale is one of time units (tones) that occurred with a period of 15 seconds, so it is not surprising that almost without exception the data for peripheral subjects with one piece of problem information present and for the central subjects with one and two pieces present fall in the 1 time unit case. Values of $\Lambda(t)$ for the following cases are plotted:

Fig. IV.1	(C, 3, S)	Fig. IV.6	(C, 5, R)	Fig. IV.11	(P, 4, S)
Fig. IV.2	(C, 3, R)	Fig. IV.7	(P, 2, S)	Fig. IV.12	(P, 4, R)
Fig. IV.3	(C, 4, S)	Fig. IV.8	(P, 2, R)	Fig. IV.13	(P, 5, S)
Fig. IV.4	(C, 4, R)	Fig. IV.9	(P, 3, S)	Fig. IV.14	(P, 5, R)
Fig. IV.5	(C, 5, S)	Fig. IV.10	(P, 3, R)		

It should be noted that the points furthest to the right on these curves, where the variability is the largest, are not reliable. This is the tail of the distribution where there are only 1 to 3 cases out of totals of 50 to 200; hence, small fluctuations, 1 or 2, effect large changes in $-\log_e \left[1 - F(t)\right]$. Our discussion, therefore, will center about the nature of these curves, omitting the last one or two points.

There are six qualitative facts about these curves that seem noteworthy:

A. All of the curves are approximately straight lines with the exception of the (_, 5, S) cases, which are slightly concave downward.

B. For C, the average slope of the R curves is greater than that of the corresponding S curves; this is most marked in (C, 3, _). For P, the two sets of slopes are about the same except for (P, 5, _), where the R slope is considerably larger than the S slope.

C. There appears to be a tendency for the R slope to decrease with large values of time. This is most convincing in (P, 5, R), but it is also suggested in some of the other R cases.

D. An increased slope over trials is evidenced in all the P cases except (P, 5, S) and possibly (P, 4, S). There is little doubt that the greatest coherence over trials is exhibited in the (P, 5, S) curves.

E. For all S curves there is a slow decrease in the slope with increased information present.

F. For all S cases the C curve has a slightly larger slope than the corresponding P curve. The same is true for the R cases with the exception of (_, 5, R).

One could accept all of these facts as phenomena and thus close the time aspect of this work; however, reasons can be adduced to indicate that not all of them need to be taken as independent. In the following sections we shall take several of these facts as basic and attempt to show that the others arise in a natural fashion from them. The analysis is based in part on plausible verbal arguments which may be subject to considerable error.

3. SENDING VS RECEIPT

Our breakdown of the data into the S and R cases is a commitment to select one of these factors as the basic trigger for sending messages. It may be that the triggering phenomenon is more complex than either of these, yet intuitively one feels that one or the other must account for a large part of the phenomenon, and that any other influence will be in the nature of a minor perturbation on the major effect. To some degree this feeling will be substantiated if we find that one can be explained in terms of the other, and if the properties of the basic one are comparatively simple.

For this experiment, it is our impression that the S curves are more basic than the R curves. We shall present three arguments for this belief: two in this section, based on considerations of plausibility, and an extended one, in the following sections, which attempts to account for characteristics of the R curves in terms of those of the S curves.

First, in statement C it was pointed out that the slopes of the R curves apparently decrease with time; thus, if they are basic, one must conclude that while the initial decision probability density is high a failure to reach a decision results in a decreasing decision probability density. But these decisions are not weighty and their delay will lengthen the experiment for the subject, so that one would expect, on the contrary, to find an increasing probability of reaching a decision.

Second, consider the curves (P, 5, _). For the S case there is no change over trials, while for the R case there is a significant change over trials. Thus, if we accept the R case as basic we must account for the constancy of the S curves in terms of the changing R curves; whereas the situation is reversed if the S case is basic. A constant phenomenon interacting with a varying phenomenon ordinarily will produce a varying outcome; but it is far more rare for a varying phenomenon to interact with another varying phenomenon with such perfect cancellation as to produce a constant outcome.

Counter to these two considerations based on the data is the strong intuitive feeling that, by and large, messages are stimulated by incoming messages that either demand an answer or that alter the problem situation. This may very well be the case in an underload communication circuit, but if the load is usually ample, as apparently it was in this experiment, then it is plausible to suppose that the limiting factor is the preparation of messages. That is to say, we are not denying that the incoming information is a relevant stimulus but simply remarking that it is ever present and that the flow of messages is in effect determined by the production of messages.

We turn now to an explanation of some of the phenomena pointed out in section IV.2.

4. RECEIPT AND SENDING SLOPES

In the following three sections we shall assume the S curves are basic, and as an approximation to the curves we take $\Lambda(t) = \lambda t$, except where explicitly stated to the contrary. This approximation is sufficiently good that it should not do violent injustice to our somewhat qualitative arguments.

The first problem that we shall take up is contained in statements B and C (section IV.2): the slope of the center R curve is initially larger than the corresponding S curve, and the former decreases with time. While we will present our argument only for the case of the center man when he has three pieces of problem information, we believe that the phenomena are similar in the other center cases. These three pieces of information are the center man's own input information and the input information of two peripheral subjects. It has been shown in section III.2 that the probability that a peripheral subject sends his first message to center is approximately 1/2, and we pointed out (section IV.2) that the first messages almost always occur in the first time unit. Thus it is very likely that every subject will send a first message at the same time unit and that, from the peripheral subjects, two messages will be directed to the center and two will not. This leads to the four topologically different cases shown in Fig. IV.15. Each of the nodes have been labelled C, P, or B, according to whether the node has new information for the center alone, for the adjoining peripheral node alone, or for both. It is known (section III.4) that if a subject has new information for only one other subject the probability of sending the next message to him is high, of the order of 0.95. Though the B case was not well understood, it was observed that the tendency

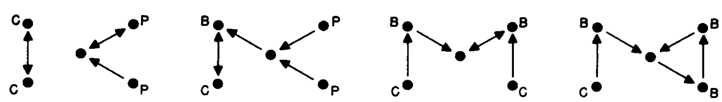

Fig. IV.15

to alternate from previous choice was of the order of 0.65. If we take the first to be 1.00 and the latter 0.65 and examine all possible cases arising from those in Fig. IV.15 we find that with probability 0.75 either one or two peripheral subjects send to the center, and the other three or two to the adjoining peripheral subjects. Thus, if we examine in detail these two cases we shall have an understanding of a fair percentage of the cases that actually arise experimentally. This we shall do.

Consider the former case. Let the time constant of the center man be λ and of the peripheral men ρ. Let the time of sending of the second message from center be t, and the time of sending of the second message of the peripheral man who sends to center be τ. If, for $\tau < t$, we assume no other message arrives at the center between τ and t, then the time δ between center's most recent receipt and t is given by

$$\delta = \begin{cases} t - \tau, & \text{if } \tau < t \\ t, & \text{if } \tau > t \end{cases}$$

It is clear that all of the following argument will be in error for large δ, since this will include cases when τ is much larger than t, hence the assumption that no other messages reach the center node is likely to be false.

The gist of our argument should now be apparent: if the center man sends his message so promptly that the peripheral man has not sent his, we shall, in general, get a small value of δ. If he fails to be faster than the peripheral man, then we begin measuring δ not from 0 but from τ, the time of arrival of the peripheral message. Thus loading the R curves at the small values of time gives a $\Lambda(t)$ with a larger slope in this case than in the case of the S curves. We shall carry out the mathematical argument in these two dominant cases to show that the correction we obtain is of the right order of magnitude.

In the case $\tau > t$, we simply write the probability that the center man sends a message at t times the probability the peripheral man failed to send his prior to t, that is,

$$\lambda \exp(-\lambda t) \left[1 - \int_0^t \rho \exp(-\rho x)\, dx\right] = \lambda \exp[-(\lambda+\rho)t] = \lambda \exp[-(\lambda+\rho)\delta]$$

In the case where $\tau < t$ we write the probability that the peripheral man sends a message at τ times the probability that the center sent his at $t = \tau + \delta$, $\delta \geqslant 0$, and sum over all τ:

$$\int_0^\infty \lambda \exp[-\lambda(\tau+\delta)]\, \rho \exp(-\rho\tau)\, d\tau = \frac{\lambda\rho \exp(-\lambda\delta)}{\lambda + \rho}$$

For the combined distribution of these two cases we obtain

$$\lambda \exp(-\lambda\delta)\left[\frac{\rho}{\lambda+\rho} + \exp(-\rho\delta)\right]$$

whence, from Eq. 3, we have

$$\lambda(\delta) = \lambda\left[\frac{\rho + (\lambda+\rho)\exp(-\rho\delta)}{\rho + \lambda\exp(-\rho\delta)}\right] \tag{4}$$

In the case of two peripheral men sending to center at times τ_1 and τ_2, and the center sending at time t, we define

$$\delta = \begin{cases} t, & \text{if } t < \tau_1 < \tau_2 \\ t - \tau_1, & \text{if } \tau_1 < t < \tau_2 \\ t - \tau_2, & \text{if } \tau_1 < \tau_2 < t \end{cases}$$

Using the known fact that the distribution of the latest of two selections from a distribution f is $2f(t)\int_0^t f(x)\,dx$ and the distribution of the earliest is $2f(t)\left[1 - \int_0^t f(x)\,dx\right]$, we can, in the same manner as above, obtain the distribution of δ and compute $\lambda(t)$ from Eq. 3. We obtain

$$\lambda(\delta) = (\lambda + 2\rho)\left[\frac{\dfrac{2\rho^2}{(\lambda+\rho)(\lambda+2\rho)} + \dfrac{\rho}{\lambda+2\rho}\exp(-\rho\delta) + \left(1 - \dfrac{\rho}{\lambda+3\rho}\right)\exp(-2\rho\delta)}{\dfrac{2\rho^2}{(\lambda+\rho)\lambda} + \dfrac{\rho}{\lambda+\rho}\exp(-\rho\delta) + \left(1 - \dfrac{\rho}{\lambda+3\rho}\right)\exp(-2\rho\delta)}\right] \tag{5}$$

If we now turn to the data to estimate values of λ and ρ for trial block 25-27, for example, we find

$\lambda = 0.765, \quad \rho = 0.888$

Computing $\lambda(0)/\lambda$ for the two cases, Eqs. 4 and 5, we obtain 1.54 and 2.08, which compare reasonably well with the observed ratio of the R to S curves of 1.63.

Furthermore, observe that in both of these cases

$$\lim_{\delta\to\infty} \lambda(\delta) = \lambda$$

Now, while it is true that these equations are accurate only for small δ, the only effect of added messages to the center will be to eliminate some of the larger values of δ, thus increasing the trend indicated. That is, from this argument we should certainly expect the slope of $\Lambda(t)$ to decrease with increasing t. This was observed to be the case in statement C of section IV.2.

For the center with more information present, the same argument applies to explain both the fact that the R curve has a larger initial slope than the S curve and that there is a decrease in slope of the R curve with time. We cannot carry out the corresponding analytic discussion because of the richness of possibilities. A very similar argument applies to the peripheral men except that it must be tempered by the fact that the average number of incoming messages during the trial is fewer than for the center. It is thus possible, if we assume that sending is the triggering mechanism, for a peripheral man to send two or more messages prior to receiving one, thus loading the distribution for large t. From these considerations we would expect the increase of initial slope to be less marked for the peripheral men, and, indeed, it may not be increased at all or could even be decreased slightly. This is seen to be the case; see statement B.

5. CHANGES OF SLOPE OVER TRIALS

The next problem to be dealt with is part of statement D: the (P, 5, S) curves are invariant over trials, and the (P, 5, R) curves have an increasing slope with trials. We shall describe a way in which this may come about, but we have not been able to carry out any calculations to show that the effect is of the right order of magnitude. The difficulty in making it precise is essentially the same difficulty as that involved in applying the argument of the preceding section to cases other than (C, 3, _). By the time a group has arrived at the state in which a peripheral man has five pieces of problem information, the number of possible histories is far too great to permit carrying out an exhaustive examination of cases. What we can do is to look at one fairly typical case and see what the effect is on it.

We take the case when the peripheral subject receives the final piece of problem information from the center man. It is then not unlikely that this message from the center is the last message received by the peripheral man before he sends a message to the adjoining peripheral man. The pattern of message sending by the peripheral man would be represented by Fig. IV.16. Let us say that this is for trial block 16-18.

Now consider a later trial block, 25-27, for example. We know from the data that very little change occurs in the time characteristics of the center man over trials, so that if a particular timing of center messages was likely in trials 16-18, it is equally likely in trials 25-27. However, the data for (P, 2, S) indicate a sharp increase in the

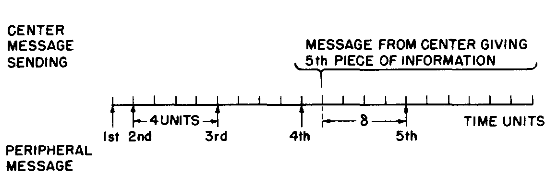

Fig. IV.16

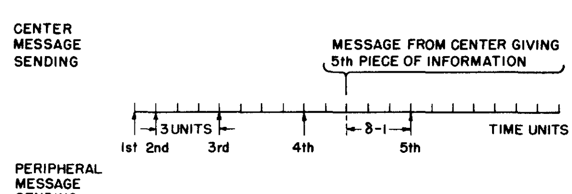

Fig. IV.17

slope (reduction in mean latency) over trials, which we shall accept as a characteristic phenomenon of the subjects' behavior. The same effect occurs, but to a lesser degree, when three and four pieces of problem information are present, but not when there are five. As seen in Fig. IV.17, the shortening of the S intervals for early decisions in the case of the peripheral men can lead to an effective shortening of the R interval for the center man when there are five pieces of information, even though there is no corresponding reduction of the (C, 5, S) mean time.

6. CURVATURE OF $\Lambda(t)$

There are few who would quarrel with the statement that as the amount of information to be dealt with increases, the value of λ in $\lambda \exp(-\lambda t)$ should be expected to decrease, that is, the mean latency will increase. The simple fact is that it takes longer to write the input information for five men than for one or two, and so it is a reasonable statement that in no way establishes the relation between the information state and the value of λ.

It is less apparent from intuitive considerations that the shape of the latency distribution should also change with increasing information; yet this is clearly the case as we pass from two to five pieces of information. The (P, 2, S) is reasonably near a straight line, but the bow in (P, 5, S) is unmistakable.

We shall give a tentative explanation; it is unsatisfactory in that no check of its basis has been made but it has, at least in one case, remarkable predictive ability.

Let us suppose that there is such a thing as a "psychologically elementary" decision which has a latency, described by the distribution $f(t)$. We have in mind a class of decisions abstracted from particular details in a manner similar to the "bit" of information theory, but we do not, at least for the present, propose the information theory notion itself for this purpose. Further, let us suppose that any nonelementary decision is composed of some number n of elementary decisions and that these n decisions are executed serially. We do not know how to characterize n. If we think of a decision about m equally likely events, information theory would characterize n as $\log_2 m$. For the moment, the important problem is not how to characterize n, but the assumption that these decisions are made serially. If this is the case, the distribution of latencies for a decision of complexity n is the probability that the first decision is made at τ_1 times the probability that the second is made at time $\tau_2 \ldots$ times the probability that the n^{th} is made at time t and summed over all admissible values of the τ's. That is,

$$f_n(t) = \int_0^t \cdots \int_0^{\tau_2} f(\tau_1)\, f(\tau_2 - \tau_1) \ldots f(t - \tau_{n-1})\, d\tau_1\, d\tau_2 \ldots d\tau_{n-1}$$

If we suppose $f(t) = \lambda \exp(-\lambda t)$, then we have

$$f_n(t) = \frac{\lambda^n t^{n-1}}{(n-1)!} \exp(-\lambda t)$$

for which

$$\Lambda(t) = \lambda t - \ln \left[1 + \lambda t + \ldots + \frac{(\lambda t)^{n-1}}{(n-1)!} \right]$$

If in this group situation we take the presence of two pieces of information to represent an elementary decision, then from the information theory point of view the five pieces of information represent, approximately, the case n = 2. The (P, 2, S) case for trial block 1 is well approximated by an exponential with $\lambda = 0.67$. In Fig. IV.18, the plots of (P, 5, S) and $\lambda t - \ln(1 + \lambda t)$ for $\lambda = 0.67$ show a striking correspondence, considering that there are no adjustable parameters. While the correspondence is not perfect, the theoretical curve being a little too shallow, it is sufficiently good to warrant further research on the problem. Clearly, the present data are not ideally suited to such fine distinctions, since they are contaminated by the other factors at work in the group. Research will have to be carried out to see if an elementary decision can be defined, and if it can be, to characterize its latency and to define a decision of complexity n.*

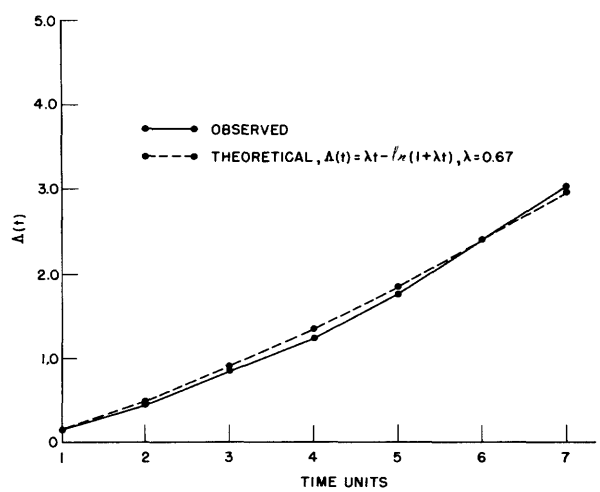

Fig. IV.18

Observed and theoretical curve for (P, 5, S) in trial block 1.

*More detailed suggestions in this direction have been presented by L. S. Christie and R. D. Luce: Suggestions for the Analysis of Reaction Times and Simple Choice Behavior, to be published by Bio Systems Division, Control Systems Laboratory, University of Illinois, 1954.

7. THE TIME CHARACTERISTICS FOR A THEORY OF INFORMATION FLOW

An attempt to formulate a theory of information flow was presented in section IV.9 of reference 1. The equations governing the flow could not be obtained because of serious mathematical difficulties. A principal source of these difficulties was the assumption that message sending is stimulated by the receipt of messages. Since we have shown that at least for the present experiment this is not the case, but rather that stimulation by sending occurs, it may be worthwhile to reconsider the model.

If we assume that stimulation by sending and a time characteristic independent of the information are present at the node, the time characteristics of the individual behavior are independent of the decision characteristics, but not conversely. The second of these assumptions is not strictly true, as we have seen, but we shall make it as an approximation to reality. We shall deal with the time problem only. The assumptions that have previously been considered for the decision process are, in the light of the present experiment, clearly inappropriate. Our previous considerations were in terms of an assumption that choice by i of j as the destination of his message depends on the set of information present at i at the time of sending. In section III.4 we saw that this choice depends on the logical difference between what i has and the union of what he has previously sent to and received from j. No theory has yet been developed embodying this much more complicated assumption.

As to the time problem, we assume that a node i has a fixed latency $f_i(t)$ and a given constant τ_i such that the first message sending is governed by $f_i(t - \tau_i)$, and if i sends a message at time τ the distribution of the next sending is governed by $f_i(t-\tau)$. We may, without loss of generality, take $\tau_i = 0$. The probability density that a message is sent at time t and that it is preceded by n - 1 sendings at times $t_1, t_2, \ldots, t_{n-1}$ is

$$f_i(t_1)\, f_i(t_2 - t_1) \ldots f_i(t - t_{n-1})$$

Thus the density of the same occurrence, but without specifying the times, is

$$g_i^{(n)}(t) = \int_0^t \ldots \int_0^{t_3} \int_0^{t_2} f_i(t_1)\, f_i(t_2 - t_1) \ldots f_i(t - t_{n-1})\, dt_1\, dt_2 \ldots dt_{n-1} \tag{6}$$

Finally, the density function $g_i(t)$ that node i sends a message at time t is given by summing Eq. 6 over all possible values of n

$$\begin{aligned} g_i(t) &= \sum_{n=1}^{\infty} g_i^{(n)}(t) \\ &= \sum_{n=1}^{\infty} \int_0^t \ldots \int_0^{t_3} \int_0^{t_2} f_i(t_1)\, f_i(t_2 - t_1) \ldots f_i(t - t_{n-1})\, dt_1\, dt_2 \ldots dt_{n-1} \end{aligned} \tag{7}$$

Equation 7, while apparently quite formidable, is actually very simple in certain important cases. For the family of distributions

$$f(t) = \frac{\lambda^{k+1}\, t^k}{k!} \exp(-\lambda t), \quad \text{we have}$$

$$g_i^{(n)}(t) = \frac{\lambda^{n(k+1)}}{(k!)^n} \exp(-\lambda t) \int_0^t \cdots \int_0^{t_3} \int_0^{t_2} t_1^k (t_2 - t_1)^k (t_3 - t_2)^k \cdots$$

$$(t - t_{n-1})^k \, dt_1 \, dt_2 \cdots dt_{n-1}$$

$$= \frac{\lambda^{n(k+1)}}{(k!)^n} \exp(-\lambda t) \int_0^t \cdots \int_0^{t_3} t_2^{(2k-1)} B(k+1, k+1) (t_3 - t_2)^k \cdots$$

$$(t - t_{n-1})^k \, dt_2 \cdots dt_{n-1}$$

$$= \frac{\lambda^{n(k+1)}}{(k!)^n} \exp(-\lambda t) \int_0^t \cdots \int_0^{t_4} t_3^{(3k+2)} B(k+1, k+1) B[2(k+1), k+1]$$

$$(t_4 - t_3)^k \cdots (t - t_{n-1})^k \, dt_3 \cdots dt_{n-1}$$

$$= \frac{\lambda^{n(k+1)}}{(k!)^n} \exp(-\lambda t)\, t^{n(k+1)-1} \prod_{i=1}^{n-1} B[i(k+1), k+1]$$

where $B(m,n) = \int_0^1 x^{m-1} (1-x)^{n-1} \, dx$ is the beta function. Since k is an integer we have

$$\prod_{i=1}^{n-1} B[i(k+1), k+1] = \frac{k!\, k!}{(2k+1)!} \cdot \frac{(2k+1)!\, k!}{(3k+2)!} \cdots \frac{[(n-1)k + n-2]!\, k!}{(nk + n-1)!}$$

$$= \frac{(k!)^n}{(nk + n-1)!}$$

so

$$g_i^{(n)}(t) = \frac{\lambda^{n(k+1)}\, t^{n(k+1)-1}}{(nk + n-1)!} \exp(-\lambda t)$$

and summing

$$g_i(t) = \lambda \exp(-\lambda t) \sum_{n=1}^{\infty} \frac{(\lambda t)^{n(k+1)-1}}{[n(k+1)-1]!}$$

We have only to evaluate the sum. It can be shown[*] that

$$\phi(x) = \sum_{n=0}^{\infty} \frac{x^{nj}}{(nj)!} = \frac{1}{j} \sum_{i=1}^{i} \exp(\rho_i x)$$

where ρ_i are the j^{th} roots of unity. Taking the derivative we have

$$\frac{d\phi(x)}{dx} = \sum_{n=1}^{\infty} \frac{x^{nj-1}}{(nj-1)!} = \frac{1}{j} \sum_{i=1}^{j} \rho_i \exp(\rho_i x)$$

whence

$$g_i(t) = \frac{\lambda \exp(-\lambda t)}{k+1} \sum_{i=1}^{k+1} \rho_i \exp(\rho_i \lambda t)$$

where now the ρ_i are the $k+1^{st}$ roots of unity.

For k = 0, 1, 2 we may evaluate this in more familiar terms:

$$k = 0: \quad g_i(t) = \lambda$$

$$k = 1: \quad g_i(t) = \frac{\lambda}{2} [1 - \exp(-2\lambda t)]$$

$$k = 3: \quad g_i(t) = \frac{\lambda}{3} \left[1 - \exp(-3/2\, \lambda t) \left\{ \cos \frac{3^{1/2}}{2} \lambda t - 3^{1/2} \sin \frac{3^{1/2}}{2} \lambda t \right\} \right]$$

It is of interest to observe that in each of these cases the rate of sending is a constant after a short period of build up, the value of the constant depending on k.

While this formulation seems to give a promising first approximation to the time characteristics of certain communication situations, it is no more than a first approximation and for some situations it is not even that. As we mentioned previously, we have reason to believe that the assumption that the sending of a message is the stimulus

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[*]Dr. Albert Blank of the University of Illinois pointed out to us the closed form of this series and he developed a proof of it. In outline it depends on the fact that

$$\sum_{i=1}^{j} (\rho_i)^k = 0$$

when ρ_i are the j^{th} roots of unity and k is any positive integer less than j. Expanding $\exp(\rho_i)\, x$ in the usual exponential series, regrouping, and using this fact yields the result.

for the next sending is only valid in cases of relatively high message load. Clearly the model discussed above also depends on this assumption, and its validity must be carefully checked in future applications. Further, we have seen earlier that the time constant, and, indeed, the form of the latency distribution, changes as a function of information present at the node; in the model we have assumed that no such dependency exists. To incorporate it will require the development of a model for the message sending decision process, and while we have some of the principal assumptions of such a model (see chapter III) their formulation into a satisfactory mathematical statement has not been effected.

8. SUMMARY

If we accept the arguments and explanations of sections 3-6 of this chapter, then by taking the S case as basic we have accounted for all the features of the time data pointed out in section IV.2 except for the following statements:

1. The (_, 2, S), (_, 3, S), and (_, 4, S) $\Lambda(t)$ curves are approximately straight lines.
2. The (P, 2, S) and (P, 3, S) curves show an increase in slope with trials.
3. For all S cases the C curve has a slightly larger slope than the corresponding P curve.

These three facts we shall accept as phenomena. An explanation of the first must rest on an adequate theory of the decision process of the individual. For the other two, one has the intuitive feeling that they are reasonable. In the second, the peripheral subjects learn that their behavior when they have only two or three pieces of information should be to send to the person whom they know does not have one or more of the pieces they have, and this they come to execute more rapidly with experience. In the third, it is clear that the center man is certainly more loaded with message traffic than the peripheral men and so, in all likelihood, he makes a conscious effort to write and send messages rapidly. Thus we find a larger slope.

It is important that we have again found that simple decision processes involve an approximately exponential latency. This function has such simple properties that there continues to be some hope of a fairly complex model of information flow being mathematically tractable. Of at least equal importance from the model point of view is the unexpected finding that the S curves are in some cases more basic than the R curves.

Chapter V. QUESTIONNAIRE RESULTS

1. NETWORK KNOWLEDGE

Although the task in this experiment did not require that the subjects have any knowledge of the communication network for its completion, as we pointed out in sections III. 3 and III. 5 an adequate knowledge could have resulted in more rational decisions. That we should expect some network knowledge follows from previous work (1) in which the subjects were not allowed any message content beyond problem information. In the present experiment this basis for knowledge of the network still remains, and in addition the subjects were free to inquire of one another about the network. The failure of the subjects to make the more rational decisions possible with complete network knowledge suggests that their knowledge was either incomplete or unused. We shall ascertain the degree of incompleteness.

Our data are based on the check list of page 1 of the questionnaire (Appendix 2) which was administered after each phase of the experiment. Since it was administered without prior warning after the first phase it could have had no influence on the subjects' behavior during this phase; however, its contents were known to the subjects during the conditioning and test phases and this knowledge may have increased the amount of discussion of the network during these periods. Some of the observed increases in network knowledge are a result of this factor; but not all are, since greater experience (each phase being five trials longer than the preceding one) also had its effect.

It is reasonable, and it has been found true in the past, that the accuracy of network knowledge is a function of the remoteness of the links from the subjects. We are thus led to a classification of the links in terms of their remoteness from a position. There are four classes:

a. Direct out (D. O.): Those links over which a person could send messages.

b. Direct in (D. I.): Those links over which a person could receive messages.

c. First degree indirect in (1st InD): Those links not in a which are D. I. to a node that could send directly to the node under consideration.

d. Greater than first degree indirect in (> 1st InD): All links not included in the other three categories.

Receiving, rather than sending, channels have been emphasized in this classification for it is on the basis of received messages that the subjects must draw inferences and receive explicit information about the network. Particularly in the third phase, there is a considerable number of explicit messages concerning links that we may call "first degree indirect out" and which in our classification often fall in the fourth class; thus, we must not be surprised if the last class is sometimes reported more faithfully than the third.

Before reporting the data we must first concern ourselves with a way to report them.

Since the subjects' answers* and the existence of links are both two-valued variables, a fourfold table and a standard statistical device such as the contingency coefficient is suggested. This coefficient, however, neglects whatever information the subjects may have had about the proportion of open channels in any one of the classes because that information is contained in the marginal frequency split, while the contingency coefficient measures the relation between two dichotomous variables given the marginal distributions. We should like to measure both aspects of the information contained in the questionnaire, and preferably the measure should be additive.

To do this we shall compare the subject behavior with certain chance models. First, let p be the probability of a correct choice when there is an equiprobable random assignment of choices to open and closed channels. Second, let p' be the probability of a correct choice when there is a random assignment of choices to open and closed channels, but with the expected marginal frequencies equal to the observed frequencies of the subjects' reports. Finally, let p" be the actual proportion of correct choices made by the subjects. We see, then, that the information transmitted by the frequency split depends on the inequality of p and p', that transmitted by the contingency on the inequality of p' and p", and the total information transmitted on the inequality of p and p". For this type of situation Goldman (2) has suggested $H = \log_2 x/y$, which has the desired additive property, as a measure of the information transmitted.

The value of H was calculated for the three cases; for the first case – the information in the frequency split – it was near zero in most cases, which indicates that, in general, network knowledge was something other than knowledge of the frequency of open and closed channels. A notable exception appeared for "first degree indirect in links" during the third phase, for the center men of the C configuration. The value of the information in the frequency split was -0.229 bits per response, which with a contingency information of 0.217 adds to a total information content of -0.012. In other words, these men had a grossly erroneous impression of the network, reporting many more open channels than existed, and this resulted in negligible total information even though there was some contingency. Since such exceptions are relatively minor, we shall present results only on the total information.

The results for the first phase are shown in Table V.1. As before, all groups for this phase are lumped. There is, as expected, a decrease in information about the network with increasing remoteness of links. Knowledge of the D.O. links is nearly perfect, as would be expected, but that of D.I. links is only two-thirds as great. This apparently surprising result probably stems from two related factors. The experimental table itself did not show which ones of the incoming channels were blocked, as it did, by the cardboard fillers, for the outgoing channels. Thus, knowledge of incoming links is based on the existence of incoming messages the frequency of which may be

*The small frequencies in the "don't know" category were equally split between positive and negative report categories.

very low. Indeed, the fact that no messages have been received over a link does not constitute proof that the link is closed. Beyond the first indirect links there is essentially no knowledge, and for the first indirect links there is about half the amount of information as for D.I. links. These results accord with those of previous experimentation, as was anticipated.

The results for the conditioning phase are shown in Table V.2. The reports of the Pinwheel subjects are more informative than those following the first phase, which may be the outcome of more experience or of some active seeking of network information or of both. The average H values throughout this phase are greater than those in the first phase.

Both Star positions are uniformly above the average, particularly the center position, which suggests that this structure is easier to learn. This stems, in part, from the fact that the most difficult category is nonexistent in the Star, but it must also be true that those which do exist are comparatively transparent.

The results for Diablo are similar to those for Star except for the reports on 1st InD links. These two entries are the outstandingly deviant ones in the table. One must conclude that there is virtually no knowledge of these links. This conclusion means that the center men fail to realize that the network consists of two internally connected sides that are connected only through them; and that the peripheral men do not have any realization of links beyond their half of the network. The latter fact about peripheral men leads to serious failings for first messages, as we have shown in section III.2; but does not for later messages, as we have shown in section III.4. This incomplete knowledge of the center men prevents fully rational behavior on their part. These explanations agree with the observations of section III.5.

Table V.3 presents the same quantities for the test phase of the experiment. There is no network change from the second to third phase for configuration D; we see in this case a general increase in network knowledge for the last over the middle trials, with a dramatic rise for reports of 1st InD links by the center. The averages also show increases in three of the categories, but a decrease in 1st InD. There can be little doubt of the difficulty the subjects had in appreciating the structure of Diablo, but we may conclude that the centers gradually do learn it.

The average information content for >1st InD is both twice as great in the test phase as in the conditioning phase and greater than the content for 1st InD on the test phase. At first this seems surprising, but it is not when we realize that the "more distant" links in Diablo are those over which a node which is connected to the node under consideration may send messages. Very often a person will ask, "Who are you connected to?", and the response will be "I can send to...," which tends to increase knowledge in the ">1st InD" category.

The D' subjects do not do as well as D, except D' center on D.I. links and D' previous center on 1st InD links. It may be that the former is due to consciousness of a change from a peripheral to a central position, and the latter to the high message activity of the previous centers as compared to other peripheral positions, which we have attributed to an attempt to maintain a dominant role. The patterns of S' and D' are similar, with the previous centers in both cases having more adequate knowledge than the other peripheral subjects. The best record of all are the S centers, although they have as much difficulty with the 1st InD links as the best of the other groups.

It is worth noting that groups that do best on 1st InD (S and S') devote a greater portion of their nonproblem content to network information than do other groups (Table II. 5 in section II. 6).

A clear perception of the network in the test phase could have been a useful guide to the center men, for once they realize that the peripheral subjects are connected in pairs and the two pairs are isolated it is clear that they need only send all the problem information once to each side and not to both people on either side. However, as we pointed out in section III. 5, even without this knowledge they will, on the average, send their second answer messages to the opposite side two-thirds of the time. The amount of information even in the best case (0. 502 bits) is not great enough to suggest that the average center man has this clear a picture of the situation, and so we should not be surprised by the earlier finding that side-to-side alternation is only slightly, if at all, above the chance value. On the other hand, some of the center men are distinctly above the average in network knowledge and the question arises: Was their behavior more rational? We divided the center men into two exhaustive categories on the basis of their performance on the last three trials of the test phase. In one we placed those who were "rational" in the sense that they invariably acted in one of several "rational" ways,* and the others we called "irrational." Network knowledge, in terms of the percent of indirect links correctly reported, was tabulated in each case and averaged over the category. The percentages were 57. 5 and 54. 2 in the "rational" and "irrational" categories, respectively. It does not appear that network knowledge was correlated with our classification, and from earlier considerations one may suspect that perseveration of behavior was a more dominant factor. This point provides some support for our policy of not giving the subjects prior network knowledge. We do not maintain that proper instructions about the network and its implications for message sending would be ineffective in changing their behavior, only that pure network information does not seem to be naturally the most important factor in their behavior for information collection tasks.

*An arbitrary decision was made for this division. If A and B are the two different sides of the Diablo network, with A representing a message to either of the two men on one side and B a message to either of the two men on the other side, we defined the following sequences of messages from center as "rational": AB, BA, ABA, ABB, BAB, BAA, ABAB, ABBA, BABA, BAAB. All other sequences were called "irrational."

2. ATTITUDES

Attitudes, as measured by relatively crude and intuitive questionnaires, have been found (1) to be a function of network position. It was expected that we would find the same type of result here, but there were two reasons to believe that it would be more subtle than before. First, action quantization in previous experiments had the vital effect that every other member of the group had to wait to send messages until the slowest member made his decision. In any centralized network the center man is usually the slowest, and so the peripheral subjects generally spent much of their time idle. A similar effect should occur when action quantization is removed, but to a less pronounced degree, since the peripheral men can send messages as frequently as they like although they may not receive information as promptly as they may wish; and in section IV. 3 we have adduced arguments to show the sending rate is nearly constant. A further consequence of the greater freedom in message sending is that in this experiment it is possible for the center men to be overloaded, which we have reason to believe reduces job satisfaction. This effect may get beclouded by an interaction between overload and subject class; that is, the center men from either the Army or the Navy may have a higher overload point, or the peripheral men in one class may be more likely to prod the center man. If such an interaction exists it will be difficult to detect it, for a separation of the data by subject class will result in embarrassingly small sample sizes.

A second reason to expect the effects to be subtle applies only to the test phase, where we shall try to detect carry-over effects from the conditioning phase. It is clear that the magnitude of the effect will be some function of the number of trials in both the conditioning and the test phases. For example, if there were but two conditioning trials and 50 test trials, it would not be surprising to find that there was no effect of the conditioning trials on the questionnaire following the test phase. We have no idea whether our choice of 10 and 15 trials was such as to give an optimum interaction between conditioning and test phase effects.

These two considerations led us to attempt to refine our measuring instrument. Since from factorial studies of the previous questionnaires we had some idea of the attitudes which are evidenced, we increased the number of items designed to measure each attitude and we used a five-point scale of agreement through disagreement in order to increase the possible range of attitude scores. Five items were used for each of three hypothesized attitudes. They are included in the questionnaire of Appendix 2. We also list them here, grouped according to attitudes and numbered as in the questionnaire.

Job Satisfaction

1. Most of the time I was bored with my job in the group.
5. I am sorry I got into this experiment.
7. I considered my job fairly pleasant.
10. I truly enjoyed my job.
14. I was satisfied with my job while I was doing it.

Effectiveness of Organization

2. I was disappointed with the way my group organized its work.
4. Our group organized its work about as well as most groups would.
9. The organization our group developed was very effective.
11. Our group just didn't get organized.
13. The organization our group had was pretty good.

Quality of Performance

3. Our group did well in getting right answers to the problems.
6. I feel that several of the answers the group got were wrong.
8. Our group may have gotten most of the answers right, but I doubt it.
12. I'm sure our answers were correct.
15. Our group did as well as the average group would do in getting the right answers.

Each administration of the questionnaire was separately factor-analyzed to determine whether or not the group of items for each attitude constituted a unitary set. In each case the job satisfaction items and the effectiveness of organization items showed a strong first centroid factor and little else. A second factor was extracted in each case, but it was weak and seemed adequately named as "positive vs negative wording." It was considered reasonable to take an average of the items as the attitude score, letting the positive and negative contributions of the second factor approximately cancel each other.

The quality of performance scale did not have a satisfactory unitary character in that two centroid factors of significant size were obtained. No rotation was necessary in order to interpret them as "an absolute judgment of performance" and "a relative judgment of performance," the latter probably containing a "level of aspiration" component. The factor patterns are shown in Table V.4.

We shall now examine the results of the conditioning phase in some detail; here we need only worry about present position and not about any carry-over effects. It will be recalled that in the action quantized case we established a strong relation between job satisfaction and a measure of rate of inputs to a node. An equiprobable input value, I, is assigned to each node as the number of inputs expected per unit time when other nodes are sending one message per unit time and choose their message destinations in an equiprobable random fashion over the available channels. For our networks, I has the following values:

Network Position	I
Star center	4.00
Diablo center	2.00
Pinwheel	1.00
Circle	1.00
Diablo periphery	0.75
Star periphery	0.25

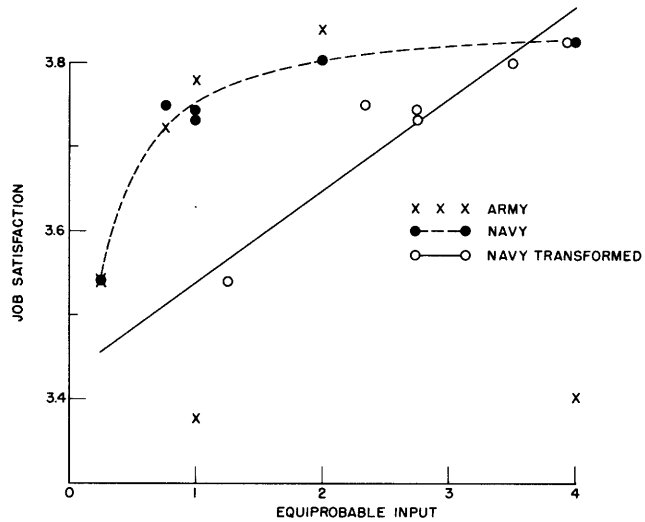

Fig. V.1
Job satisfaction as a function of inputs.

In Fig. V.1 we present job satisfaction scores vs input value, I, for Army and Navy groups separately. The smooth curve rising at a diminishing rate for the Navy groups, is reminiscent of the relation previously found between these two variables; this curve was linearized by the empirical transformation

$$\frac{1}{\pi} \sin^{-1} \left\{ 2 \frac{\exp(2I) - 1}{\exp(2I) + 1} - 1 \right\} + \frac{1}{2}$$

and we see that this again yields a linear plot. For the Army subjects, two points differ radically from the expected trend. The low point on the right is Star center and the other is Circle. The former may represent an impaired job satisfaction due to overloading, whereas the apparently more adequate Navy subjects took this pressure in their stride. This difference parallels the error rate differences between Army and Navy centers discussed in section II.5. Our only explanation for the other deviant point is speculative and rather weak. The Circle network demands a type of "democratic" self-reliance on the part of all subjects which is not demanded by the centralized structure of Star and Diablo nor really by the "anarchistic" structure of Pinwheel. This may well be less congenial to subjects of lesser ability. Such speculations further augment the desire for more adequate tools for assessing the personal traits that are relevant to task group performance.

The average effectiveness of organization scores are presented in Table V.5 arranged in descending order for Army and Navy groups separately. For the Navy groups the order follows the degree of centralization of the network, with center men uniformly giving higher ratings than the peripheral men. For the Army groups the pattern differs in that Diablo center moves ahead of Star periphery – a minor inversion – and that Star center is at the bottom instead of the top of the list – a very gross shift. This, of course, is parallel to the difference in job satisfaction, where the Army Star centers were far less satisfied than the Navy ones. Presumably the explanation is much the same in this case: The Army men, not adapting to the overload situation, feel that this is a product of bad organization.

Since the remaining two scores – relative and absolute performance – did not show patterns nicely related to network position, the data will not be presented.

We turn now to the third administration of the questionnaire. Its relations to either the conditioning or the test phase network positions are confusing, and we feel that they will not be elucidated until a more subtle measuring instrument is devised. There are, however, interesting comparisons between the two questionnaire scores, as shown by differences obtained in the following way. The second administration scores were subtracted from the third for each position history. The difference between the scores of the men in Diablo center for both the conditioning and the test trials was taken as a base line for each class of subjects that became Diablo center in the test phase. This difference was, therefore, subtracted from each of the raw differences. The same procedure was used for changes to Diablo periphery, except that the base line was taken to be the average of the differences for Diablo periphery to Diablo periphery, for both the D and D' configurations. These computations were made separately for Army and Navy groups and then averaged, since the pattern was similar in the two cases. For presentation, we have divided these adjusted differences into five categories from marked increase, through no change, to marked decrease; these are denoted by ++, +, 0, -, --. The results are shown in Tables V. 6 and V. 7.

The most striking feature of these tables is that the change to the center position includes most of the plus ratings and the changes to the periphery include most of the minus ratings. This fact, and the exceptional case, Star center to Diablo center, are reasonable in the light of our previous remarks. In detail, both job satisfaction and effectiveness of organization closely parallel the respective pertinent objective changes in network position, although in the latter there appears to be a distinctive influence of the central or peripheral character of the final position. The absolute judgments of effectiveness parallel the organization rating closely, except that there is less drop from Star center to Diablo center and a greater drop from Star center and Star periphery to Diablo periphery. The changes in relative judgments of effectiveness parallel the absolute judgment changes with the notable exception of those of the men changed from the periphery of Diablo to the center. This disparity, and also such less striking differences as the larger relative drop than absolute drop from the center of Diablo to the periphery, agree with the supposition that the relative judgments contain an element of level of aspiration; for we may expect a high level of aspiration to result from a movement toward high job satisfaction and high perceived organizational effectiveness; and these two measures do increase with a change from peripheral to central position within the same network.

3. POSITION RATINGS

On the third page of the questionnaire the subjects rated, by answering six questions, the five positions in their network. The ratings the subjects gave to their own positions were treated as item scores, and from this a matrix of intercorrelations was prepared and it was factored by the centroid method, giving five factors. The analysis was repeated three times, using communalities from the preceding analysis to stabilize the final communalities. Orthogonal rotations were performed until by visual inspection a good approximation to simple structure was obtained. Table V. 8 presents the rotated factor matrix. The first three factors represent the attitudes toward position characteristic of the three phases. Factor V is loaded appreciably only on item five, and we believe that it represents a factor of reaction to the negative phrasing of this item, the only one so worded. The fourth factor has the most complicated, but also the most useful and interesting, loading pattern. While it is not loaded on the "position pleasantness" items (1 and 4) in any administration, it does show an increased loading with administrations on the "constructive importance" items (2 and 3). On the "destructive importance" items (5 and 6) it shows appreciable loadings on the last administration, but not on the preceding two. These loadings, particularly the latter one, suggest that the factor represents a perception of the change of importance of position. The loadings on items 2 and 3 in the first administration are consistent with this interpretation if we consider that those subjects most reactive to position importance will rank highest on this factor.

Since there are no position differences in Pinwheel, differences in factor scores on the first factor represent individual differences with no relation to position. For factor II, factor scores were computed, averaged over network position during the conditioning phase; these scores are shown in Table V. 9. These results confirm the findings of the previous section on job satisfaction; indeed, the pattern is more regular and there is no difficulty arising from differences between Army and Navy Star center subjects. However, this difference between the two measures is difficult to explain. The factor III scores can be studied in terms of the differences from the factor II scores. Since this yields a similar picture to that given by the adjusted difference scores of the preceding section, it will not be presented.

Since factor V is the weakest of the five and does not seem particularly interesting no analysis in terms of factor scores will be attempted.

The pattern of factor IV scores, shown in Table V. 10, averaged over network position history, gives remarkably regular evidence of just those perceived changes in position importance that one would expect from the results for factor II. The principal characteristics of this factor are: The unchanged D and D' peripheral positions are just slightly higher than the over-all mean, and the D center positions are somewhat larger than the peripheral positions. This is plausible, since the mean score is depressed by the preponderance of peripheral men, most of whom have negative scores. The displaced center men have the largest negative scores; the new center men in D', the highest positive scores. The S center men have a negative score, reflecting the fact that the importance of position decreases in moving from Star to Diablo center; the peripheral subjects from S and S' (excluding previous center) have a positive score, an indication of gain in importance of position. The C center subjects have a small positive score, which indicates, quite correctly, that the change is not very great. In apparent exception to this reasonable pattern are the S' center men, who have a negative score, which does not agree with the increased dominance of their position. It may be, however, that they contrast their actual position in the test phase with their perception of the center position in the conditioning phase to the discredit of the former.

4. SUMMARY

The first portion of the chapter was concerned with network knowledge, in an effort to demonstrate incidental learning during the group task and to investigate the influence of this knowledge on task behavior in ambiguous choice situations. It seems reasonable to conclude from our evidence that network knowledge had little or no effect on the task behavior, and the questions raised in chapter III remain undecided. Second, we gave data on the attitudes of the subjects toward aspects of the group situation, and presented some evidence showing that task performance had some influence on attitudes, but no progress was made on the important question of the effect of attitudes on performance. Surprisingly, the influence of work on attitudes is in some cases a long-term influence which overrides more immediate task performance. To a large degree we have been able to identify the situational features that influence network knowledge, and to a lesser degree those that influence attitudes. Further research, guided by the realization that these are forms of incidental learning, should enable us to make precise the basis upon which attitudes are acquired.

We believe the questionnaire used in this experiment is a distinct improvement over the earlier questionnaires, but the job we required of it taxed it to the utmost. Further attempts to refine the sensitivity and reliability of these questionnaires are needed. A second aspect of the problem of measuring personal characteristics is to devise a means to test our subjects prior to experimentation, and to predict their behavior in the experiment from the test. A beginning on this problem has been undertaken in Technical Report 265 (ref. 4).

Table V.1

Network Information in First Phase

Link Type	D.O.	D.I.	1st InD	>1st InD
H	0.902	0.644	0.346	0.082

Table V.2

Network Information in Conditioning Phase

Network Position / Link Type	D.O.	D.I.	1st InD	>1st InD
Circle	0.927	0.687	0.375	0.176
Star Center	1.000	0.886	0.633	---
Star Periphery	0.938	0.886	0.544	0.226
Diablo Center	0.963	0.829	-0.006	---
Diablo Periphery	0.977	0.791	0.085	0.218
Pinwheel	0.908	0.816	0.496	0.131

Table V.3

Network Information in Test Phase

Configuration	Position / Link Type	D.O.	D.I.	1st InD	>1st InD
C	Center	1.000	0.849	-0.012	---
	Periphery	0.927	0.808	-0.018	0.313
S	Center	0.963	0.908	0.442	---
	Periphery	0.913	0.844	0.191	0.317
D	Center	1.000	0.808	0.502	---
	Periphery	0.971	0.913	0.138	0.233
S'	Center	1.000	0.849	0.502	---
	Previous center	1.000	0.963	0.519	0.486
	Periphery	0.989	0.829	0.404	0.390
D'	Center	1.000	0.927	0.170	---
	Previous center	1.000	0.849	0.243	0.415
	Periphery	0.938	0.778	-0.016	0.283
P	Center	0.927	0.766	0.127	---
	Periphery	0.916	0.808	0.392	0.243

Table V.4

Factor Loadings for "Quality of Performance" Items

	Questionnaire Administration					
	I		II		III	
Factor	1	2	1	2	1	2
Item						
3	0.438	-0.403	0.518	-0.457	0.528	-0.424
6	0.612	0.343	0.737	0.355	0.725	0.395
8	0.518	0.353	0.629	0.318	0.775	0.266
12	0.748	0.128	0.793	0.241	0.782	0.225
15	0.482	-0.362	0.563	-0.416	0.591	-0.412

Table V.5

"Effectiveness of Organization" Scores for Conditioning Phase

Navy		Army	
Star Center	3.96	Diablo Center	4.12
Star Periphery	3.90	Star Periphery	3.97
Diablo Center	3.70	Diablo Periphery	3.85
Diablo Periphery	3.58	Circle	3.80
Circle	3.58	Pinwheel	3.64
Pinwheel	3.48	Star Center	3.64

Table V.6

Adjusted Changes in Attitude Scores Resulting from Indicated Changes in Position History to Diablo Center

	Conditioning Phase Position				
Score	S' Periphery	D' Periphery	P	C	S Center
Job satisfaction	++	+	0	0	--
Organization	+	+	+	++	--
Absolute performance	+	0	+	++	--
Relative performance	++	++	0	++	--

Table V.7

Adjusted Changes in Attitude Scores Resulting from Indicated Changes in Position History to Diablo Periphery

	Conditioning Phase Position				
Score	S and S' Periphery	C	P	D' Center	S' Center
Job satisfaction	+	0	-	0	-
Organization	-	-	0	0	-
Absolute performance	- -	-	+	-	- -
Relative performance	- -	-	+	- -	-

Table V.8

Factor Loadings for Position Rating Analysis

		Factors				
Administration	Item	I	II	III	IV	V
I	1	479	195	019	048	-099
I	2	434	075	-088	402	-106
I	3	336	182	-076	441	-077
I	4	489	223	053	-081	-051
I	5	158	169	037	004	331
I	6	341	186	-079	157	048
II	1	106	577	192	-035	000
II	2	-115	820	-265	214	021
II	3	-279	626	-133	348	-118
II	4	167	608	180	-081	-173
II	5	-121	365	-023	-076	166
II	6	-212	634	012	011	055
III	1	039	187	584	-050	-199
III	2	032	169	553	455	122
III	3	-019	073	502	541	145
III	4	097	178	710	018	-103
III	5	-039	074	339	327	432
III	6	037	089	630	308	217

Table V.9

Factor Scores for the Desirability of Conditioning Phase Position Averaged by Positions

Star Center	0.434
Diablo Center	0.398
Pinwheel	0.060
Circle	-0.018
Diablo Periphery	-0.025
Star Periphery	-0.217

Table V.10

Factor Scores in Perception of Change in Effective Importance of Position, Averaged by Position Histories, and Ranked in Order of Magnitude

Test Phase Position					
Center		Periphery		Previous Center	
D'	0.384				
P	0.313				
D	0.198				
		S, S'	0.110		
C	0.103				
		D, D'	-0.023		
		P	-0.098		
S'	-0.109				
		C	-0.160		
S	-0.183				
				D'	-0.223
				S'	-0.246

Chapter VI. CONCLUSIONS AND GENERALIZATIONS

This brief chapter is intended not as a detailed summary of the contents of this report, but rather as a very general synopsis of the philosophy that has been evolved from these studies and as a statement of several broad generalizations that we feel are valid.

Our prototype groups are those formed by society to produce accurate information outputs in a short period of time from certain input data – information processing groups. It is the time requirement that, at least in many modern applications, necessitates a group rather than an individual to process information; for if time were of no matter the group could be replaced by a suitable storage device and a single individual or decision-making element. In some cases it is time itself that society specifies, as in many military applications, and in others the time requirement arises indirectly through economic considerations. It is also clear that the error rate of a group is related to the time requirement, at least indirectly, since in the limit in which there is no time pressure inexpensive checking procedures that permit arbitrarily good error performance can be introduced. In the design of such groups, society is very much concerned with the relation between error and time, and with the dependence of this function on the possible organizations of groups to execute the imposed information processing task.

There are many other problems of practical and scientific interest about such groups and some of them (leadership, morale, group norms, group deviants, and the like) have received attention in the literature. There can be no doubt of the importance of these factors, both to the individuals in the groups and to society. Their importance to society – in its most amoral and inhuman aspects – is only through their influence on the over-all group performance, that is, the groups' ability to process information with high accuracy in a short time. If we grant that time and errors are the basic measures of group performance, then their study is one approach to the study of task-oriented groups. It has been our approach.

A technique of study not uncommon in present day social science is to treat the group as an entity and to attempt to draw generalizations about the group as a unit. Experience in this direction suggests that it is a difficult process and that the predictive utility of such statements is limited. An alternative is to study the group as composed of individuals, and to predict the group behavior from assumptions about them, measurements of them, and the structure of the group organization. Arguments can be adduced for both techniques, but our biases led us to adopt the latter procedure.

In some ways the former method of study could have been much more direct, for we could have studied directly the relation between time and errors by running the appropriate experiments. The latter procedure – analysis with an eye to subsequent synthesis – entails knowing how both the group time and the group errors arise from individual behavior and group organization. Perhaps both of these problems could have been dealt with simultaneously, but, to say the least, we were skeptical. We decided to study groups of both modest size and simple organizational structure by running simple experiments, and from the results we hoped to develop an adequate description, in an essentially errorless situation, of the generation of group time from the individual behavior, and of group errors when time is not a critical factor. Ultimately, the two will have to be incorporated in a more elaborate description, but that stage has not yet been reached in our work.

The greater portion of published work, including this report, has been concerned with the time problem; primarily, one suspects, because it is the easier. Let us deal with it first. It may be stated quite simply: What statistical assumptions must be made, and therefore what quantities must be measured, and how should they be combined in order to predict the over-all group time characteristics? Much of the difficulty of this problem rests on obtaining an adequate description of the group organization (by adequate we mean formal, i.e. mathematical) which prescribes the way in which individual interactions compose the group result. To some degree we have by-passed this problem by taking a simple and formal first approximation to an organization: the communication network. This, in very many situations, is a real part of the organization, either by fiat, as in some military and industrial cases, or naturally through such factors as the emotional or spatial proximity of people. In general, there is much more to an organization than this, but it is common to many organizations. It is important in evaluating these studies to realize that we have made no attempt to study the influence of an imposed hierarchy or of an assignment of differential functions. It is certain that more sophisticated studies of organizational effects on the prediction of group time (and of group errors) will modify what we have found, but it seems doubtful that what we have discovered can be completely ignored. In the same vein, our experimental groups have been short-lived and composed of people who were initially unacquainted with each other; it is to be expected that long-term acquaintance of people in a group will lead to a social structure that will seriously influence the effects of the group organization. These are costs of controlled laboratory experimentation in return for which we obtain simple data in sufficient quantities so that we may, with reasonable rapidity, get to some of the basic factors in operation. This procedure gives an idea of which questions are appropriate and which probabilities are of interest in the real situations that one might want to examine.

While keeping in mind that our studies are restricted, there are several statements deriving from them that we think may be quite widely true:

A. The individual time latencies governing the sending of messages appear, to a first approximation, to be independent of the final decision made, but not of the information under consideration when it is made. In at least some of the cases the exponential function, or more generally the family of functions known in statistics as type III, serves as a very adequate representation of the latency distribution. Both of these remarks, if embodied as assumptions in a mathematical model of the group, result in appreciably simplifying the mathematics.

B. The decisions of where next to send information within a communication network do not appear to be governed by any appreciation of the total task and organizational situation, but rather they are determined by a very limited appreciation based on the information at hand and on what has been received and sent in the recent past. This holds true over a repetitious series of trials during which there is ample opportunity to assess the total situation. A little reflection will suggest that this is a very reasonable and intuitive result; in fact, it is well known to those dealing with highly structured situations that most people in the system have an incomplete and often inaccurate concept of the organization and communication links. There are, of course, exceptions. One characteristic of an exceptionally able person in a communication system may be the effort he takes to go beyond the local flow of information which the system naturally gives him, thereby attaining a level of knowledge that allows more intelligent decisions than are otherwise possible. There are also planned exceptions. In a system with one person in charge and responsible for the outcome of the group, an effort is usually made in the design of the communication network to provide him, locally, with very complete summaries of the performance of the remainder of the system. The design is an attempt to force his local information flow to be global, or total-system, information. This device has its price, for there is always the distinct possibility of creating an overload situation that effectively negates the purpose of the design.

C. The next conclusion is fundamentally mathematical, though it is far from precisely formulated. There are networks and, therefore, presumably more complex organizations, with the property that if people operate on some basis of locally optimal decisions the outcome is optimal or near optimal group performance for that network. There are other networks for which this is not the case. Finally, two networks of the same size may have different optimal group performances.

We feel that any optimism about improving the performance of large communication systems involving human beings must center in large part around the idea contained in statement C. The fault of many utopian schemes for improving organizations is their failure to accept the fact that, generally, the system must be constructed from components that react almost entirely to local features of the system; the recognition of this fact, we contend, should be a basic principle of system design.

The Star network is an example of the conventional hierarchical system; it has the property that, by eliminating any decision on the part of the subordinate (peripheral) members as to where to send messages, it tends to enforce behavior near its optimum, provided no overload occurs. This, in part, must be the charm of such an organizational structure to those who desire a rigid reliability. But in our work we have also noted that in some cases and for some tasks the Circle network also has the property that locally optimal decisions tend to lead to optimal group performance. The important point is that the group optimum for the Circle network in some of these tasks is better than that of the Star in the same tasks. There are at least three costs for this better average performance. First, there is a chance of an occasional bad performance, which is unacceptable to those who feel that uniformity at the price of mediocrity is preferable to brilliant but not completely reliable performance. Second, the time to learn appropriate behavior in a less rigid system appears to be longer. Third, and it is very relevant at the present state of the art, the conventional hierarchical system is widely applicable with little change of reliability to differing requirements and tasks; this may not be true of other organizations. There may well be networks that for some purposes are better than Star and for others are considerably poorer. We certainly do not contend that the Circle arrangement is suitable outside the laboratory, although it might be. Society has very probably hit upon a system in the hierarchy which, by and large, achieves its own optimum under a wide variety of circumstances. The contribution of a science of human systems will be the introduction of other systems having, for specific uses, this same property and a better optimum.

The directions of study seem clear: The concept of locally optimal behavior, and the measurement of what people in fact do, must be extended well beyond our modest efforts. Judging by our work, people come close to locally optimal behavior when that optimum uniquely defines the choice, but what governs their behavior when the choice is ambiguous is not clear. It has been clearly demonstrated that they do not act as if they were tossing coins, and there are indications that they rely heavily on their previous behavior in the same situation. Considerable study of these ambiguous choice situations is needed. At the same time a model must be perfected and solved – which probably means computer solutions – to demonstrate whether the factors assumed in the model do indeed give accurate predictions of the group performance.

In our studies we have simultaneously observed the individual and the group behaviors and have made it our problem to determine which of the numerous measures are relevant in describing the relation between the two. Assuming this procedure leads to a theory, it is then necessary to have methods for determining the relevant individual measures without actually creating the group. Two procedures are suggested. First, other simple measures may be made on the individuals and from these an attempt made to predict their behavior in the group. Work in this direction has been carried out recently in our laboratory (4). Second, since much of the group behavior seems to be determined by local considerations it is completely feasible to simulate the performance of the rest of the group to obtain the reactions of the individual to various situations that he will confront. This is practical only if the number of these situations is small, as it certainly has turned out to be in our experiments. In the long run the former procedure is likely to be more fruitful, but in the short run the latter is much more likely to lead to actual attempts to predict. This being done, we shall be well on the way toward a technique for solution of the synthesis problem: the design of organizations to do a task as well as possible within given time, equipment, and personnel limitations.

When we turn to the subject of group errors the picture is both more difficult and less complete. For our own thinking, we have subdivided the generation of group errors into four categories which seem intrinsically different.

1. Individual errors. In this group we include incorrect addition, the replacement of one word by another, the transposition of a pair of numbers in a series of numbers, and the like. The potential influence of these errors on the group output is clear, yet they are not inherently a part of the study of a group for they depend on an individual in ways which are probably largely independent of his interaction with others. This is a part of the province of individual psychology, and although we shall need to know an adequate way for including the possibility of individual error into any model of the group it is not a basic part of the model. Thus we feel that it is a phenomenon better studied by others.

2. Channel noise. An error in understanding a message may arise from channel noise, in the sense of information theory. Here we are thinking of telephone or radio static, radar clutter, and the like. Study of this phenomenon is being carried out by communication engineers and psychoacousticians, and in all likelihood it will be possible to incorporate their results into a group model. Little effort has been expended on this problem with groups; there are more pressing needs.

3. Coding ambiguity. A message may be misunderstood because of ambiguities in the use of the language, that is, the intent of a message may be mistaken by the receiver. This, in some respects, is closely related to channel noise, particularly in the statistical description of the phenomenon, yet it is inherently different. This can be seen in the ways by which the two are combatted: channel noise by some form of repetition; coding ambiguity by the temporary use of redundant statements until a common code or use of language is established. In a sense, this study is a part of linguistics; but it appears that the direction presently taken by linguists is such that answers in a form suitable to the group problem will not soon be forthcoming. Two studies of this source of error have been carried out by this laboratory. The first (1, 3) was not much more than a pilot study and the second, more comprehensive, experiment has not yet been analyzed. One principal, though tentative, conclusion from our published work is that highly centralized organizations do not tend to correct a high error rate caused by coding ambiguity unless there is an external feedback providing knowledge of the errors. This is in contrast to some other networks in which there is a natural internal error feedback that leads to automatic error reduction.

4. Filtering. More often than not, information processing groups serve the function of reducing a mass of input data into a form that can be accepted in a reasonable length of time by one individual. In general, portions of this initial information pass through individuals where it is "digested," that is, some of it is discarded and the remainder is recast in a form suitable for transmission to the next stage without overloading the system. This process is called filtering. It is, of course, the time requirements on the group that necessitate this activity. It is not difficult to see how filtering may lead to errors, for a person may discard, as irrelevant, information that he would keep if he were aware of certain information elsewhere in the system. The design

problem again seems to be one of adapting the organization to the task so that, on the average, locally rational decisions yield near optimal group performance. The subject of filtering is one that has often been mentioned, but so far as we know no experimental work has been completed. At the present, it seems to be the most pressing need in the study of task-oriented groups.

In closing, we shall leave the reader to ponder a most important and nebulous problem – one that points up a profound inadequacy in our work. Throughout our experiments we have used simple tasks judged to be adequate for our purposes and we have performed our analysis with the task as a somewhat implicit parameter, yet in our discussion we have continually referred to the design of an organization suited to the task. Our studies, therefore, are severely limited by their failure to examine a broader basis of tasks. The reasons are practical, for it is very expensive to make this examination experimentally until some structure or classification is given to the concept of a group task. Our analysis has certainly abstracted from the details of the task, and so must any model. The problem is to determine what abstract features are relevant and to classify tasks accordingly. Before long this problem must be given serious consideration, or the study of information processing groups will result in an elaborate but incoherent bibliography.

Appendix I.

Instructions to Subjects

This is the Group Networks Laboratory, and we are doing some experiments in communications. In a few minutes we will go into the experiment room where I will show you what you will be doing this morning, but before we start I would like to mention one general rule. There should be no talking among the five of you from now until the end of the experiment. Any conversation may mean that our results will not be accurate.

Please take any seat at this table. Notice that the section you are sitting at is identified by a letter, A, B, C, D, E. You will be known by that letter throughout the entire experiment today.

Now up on the rack at your right is a pack of cards. On the back of each of the cards there is a number which is circled and underlined in red, like this (demonstrate). For each trial of the experiment you will each have one of these numbers, but each of you will have a different number. You will have the solution to the problem when you know what number each of the other people has. In other words, you have the answer when you know all five numbers.

(The following paragraph is used for Army subjects.)

If you could talk to one another this would be easy, but as we said earlier, there will be no talking. All communication will be by messages written on these cards. Before we go into the details of the messages, let me point out why we are doing this experiment. The problem is, as you see, very simple – you each have a piece of information – a number – and the trial is completed when you know what everyone else has. This is like one part of many communication problems in the Army and the Navy. One person has some data as to the location of the enemy supply dumps ... another as to the availability of guns and ammunition ... another as to how successful our artillery is ... etc. Now, unless these pieces of information are collected together in one place, an army cannot be very effective. Not everyone can talk to everyone else. There aren't enough telephone lines laid to allow this, and anyway, this would cause too much confusion. The information must be collected in some orderly fashion, so the Army sets down a doctrine of what information shall be sent where; for example: the intelligence reports are sent to headquarters, the availability of supplies are sent to headquarters, but intelligence does not report to the person in charge of supplies. Well, sometimes these systems work pretty well and other times they do not. So we have designed this experiment to try to find out about different hookups. Now, you can see that unless you cooperate with us, even if you think the problem is awfully simple, we cannot get very reliable information on how such systems work. There is an element of seriousness to what we are doing, for a better communication system may just as well save your life as a better gun.

(The following paragraph is used for Navy subjects.)

If you could talk to one another this would be easy, but as we said earlier, there will be no talking. All communications will be by messages written on these cards. Before we go into the details of the messages, let me point out why we are doing this experiment. The problem is, as you see, very simple – you each have a piece of information – a number – and the trial is completed when you know what everyone else has. This is like one part of many communication problems in the Army and the Navy. One person has some radar data, another some sonar data, another weather information, another information concerning where our planes are, etc. Now, unless these pieces of information are collected together in one place, a ship cannot be very effective. Not everyone can talk to everyone else; there aren't enough telephone lines on board ship, and anyway, it would cause too much confusion. It must be collected in some orderly fashion, so the Navy sets down a doctrine of what information shall be sent where; for example: the sonar operator tells the bridge, the radar operator tells the bridge and the fighter controllers, but does not tell the sonar operator. Well, sometimes these systems work pretty well and other times they do not. So we have designed this experiment to try to find out about different hookups. Now, you can see that unless you cooperate with us, even if you think the problem is awfully simple, we cannot get very reliable information on how such systems work. There is an element of seriousness to what we are doing, for a better communication system may just as well save your life as a better radar.

As I said before, you will write all the messages you want to send on these cards, on the plain side, not on this side (show printed side of I.B.M. card). Notice that all the cards in your section are stamped with your letter; this will identify every message you write as coming from you. Now, you will get cards from other people, and you may want to send the information on them to someone else. You simply write what you want to send on one of your own cards; remember, you may not send on other people's cards, the only cards you send are those from your own section. Also, you see the cards are numbered 1, 2, 3, and so on. It is important that you send them in that order – just take the top one off the pile when you want to write a new message.

As I suggested when talking about Navy (or Army) communication systems, you will not be allowed to send messages to everyone in the group, nor to receive messages from everyone else. Look at the center panel in your section; there are some slots all in a row labeled "to A," "to B," etc. These are the channels through which you may send your messages. Some of these may be blocked by pieces of cardboard. These are the ones you cannot send messages through. The unlabeled slots are where messages will come to you. You can't send messages through these slots. Will you please look at your panel and see where you can send cards? We will come around and check with you to be sure you know where you may send your cards. Remember, don't talk, just point out the channels you may send through.

We don't want you to send messages just any time, but only when this "tone" sounds (demonstrate "tone"). It will sound every 15 seconds; when it does, you may send a card if you wish – you do not have to send a message at each tone – but you can only send one card each time. Even if you want to send the same thing to two different people, it will have to be done on two different tones. When you have written your message, decide where you wish to send it, and when the tone sounds, push it through the proper channel. As the card goes through the channel it will break an electrical circuit which will record that a message has been sent. Therefore, it is extremely important that you do not break the contact in the channel before you send the message. You may place the card at the mouth of the slot so that you will have no difficulty getting the card through, but do not push it in far until the signal is heard. Then push the card firmly through. Is that clear?

Here is the procedure to follow. When I say "Start," you will turn down the first card on the rack to your right. Take the first message card from the stack in your section, and write any message you think will help the whole group to get the answer. Decide where you will send this card, wait for the tone, and when you hear it, push the card through that channel. Each time the tone sounds, you may get messages, so keep your eye on the unlabeled channels. After you've sent the first card, fill out card number two and get ready to send it. You may send as many cards as you wish so long as you send only one card each time the tone sounds. In order for the group to get the answer to the problem, you will have to pass on numbers, but you can also write anything else you want to.

As soon as you know what number everyone else has, you have the answer. To signal this, push the black button on the box at your left. It is very important that you push this answer button just as soon as you know all five numbers, as we want a record of when each one of you has the answer. Write down the numbers in the appropriate places on your answer sheet as you receive them. Remember you are working as a team and just because you have the answer doesn't mean that everyone else does, so keep on sending messages and help everyone get the answer. The trial is not over until all five of you have all five numbers and have pushed the answer button. When this happens, a long buzzer will sound, and I'll tell you that is the end of the trial. We will do several trials in this fashion and then stop and you will answer a questionnaire. We will then do a second set of trials and answer the same questionnaire, and finally a third set of trials and again the questionnaire.

Now you want to get this done fast, and so do I, but simply writing furiously and sending messages indiscriminately will not speed things up. I've seen groups do that and they were the slowest we've had. This is like anything else that you want to do fast, you have to learn to do the job efficiently as well as quickly. It will make an important difference where you send your messages. I cannot tell you what you should do, but you can figure it out among yourselves.

<u>After each trial:</u>

That is the end of trial number ___. (Be sure you have your answers written down on the answer sheet.) Take all the cards which have come to you, and also any cards that you have started to write but have not had a chance to send, place them together and put a rubber band around them. (You will find rubber bands in the box in your section.) Mark a number ___ on the top card of the bunch and place the cards in the paper bag to your left.

Turn down card number ___ and start.

Appendix II.

Questionnaire

Your Name ______________________________ Date ______________________________

I was in position A B C D E (Circle One)

I. NETWORK QUESTIONNAIRE

Below are some statements that are either true or false. Make an X in the blanks to the right of each one to tell if it is true or false. If you don't know but have a hunch, make a guess. Your guesses are more likely to be right than wrong. If you don't know at all, make your X in the space for "don't know." You must make <u>one</u> X for each sentence.

If you think that a drawing would help, you may make one in the space below.

	True	False	Don't Know
A could send cards to B	____	____	____
A could send cards to C	____	____	____
A could send cards to D	____	____	____
A could send cards to E	____	____	____
B could send cards to A	____	____	____
B could send cards to C	____	____	____
B could send cards to D	____	____	____
B could send cards to E	____	____	____
C could send cards to A	____	____	____
C could send cards to B	____	____	____
C could send cards to D	____	____	____
C could send cards to E	____	____	____
D could send cards to A	____	____	____
D could send cards to B	____	____	____
D could send cards to C	____	____	____
D could send cards to E	____	____	____
E could send cards to A	____	____	____
E could send cards to B	____	____	____
E could send cards to C	____	____	____
E could send cards to D	____	____	____

II. JOB QUESTIONNAIRE

Below are 15 statements about the work you and your group have been doing. You are to mark an X on the phrase below each statement which best describes how you feel about that statement. There are no right or wrong answers. We want your honest opinion on each one of the statements.

1. Most of the time I was bored with my job in the group.
   Strongly agree agree undecided disagree strongly disagree
2. I was disappointed with the way my group organized its work.
   Strongly agree agree undecided disagree strongly disagree
3. Our group did well in getting right answers to the problems.
   Strongly agree agree undecided disagree strongly disagree
4. Our group organized its work about as well as most groups would.
   Strongly agree agree undecided disagree strongly disagree
5. I am sorry that I got into this experiment.
   Strongly agree agree undecided disagree strongly disagree
6. I feel that several of the answers the group got were wrong.
   Strongly agree agree undecided disagree strongly disagree
7. I considered my job fairly pleasant.
   Strongly agree agree undecided disagree strongly disagree
8. Our group may have gotten most of the answers right but I doubt it.
   Strongly agree agree undecided disagree strongly disagree
9. The organization our group developed was very effective.
   Strongly agree agree undecided disagree strongly disagree
10. I truly enjoyed my job.
   Strongly agree agree undecided disagree strongly disagree
11. Our group just didn't get organized.
   Strongly agree agree undecided disagree strongly disagree
12. I am sure our answers were correct.
   Strongly agree agree undecided disagree strongly disagree
13. The organization our group had was pretty good.
   Strongly agree agree undecided disagree strongly disagree
14. I was satisfied with my job while I was doing it.
   Strongly agree agree undecided disagree strongly disagree
15. Our group did as well as the average group would do in getting the right answers.
   Strongly agree agree undecided disagree strongly disagree

III. POSITION RATINGS

Below are six questions about the five positions in your group: You must decide which position is the best answer to the question and mark that position with a 1. Then decide which position is the second best answer and mark it 2. Do the same for the third best, fourth best, and fifth best. Write your numbers in the blanks under each question. Each blank must be filled with a number.

1. Which was the most pleasant position to be in?

   D____ E____ C____ A____ B____

2. As far as getting the answer to the problems, which was the most important position in your group?

   C____ D____ A____ B____ E____

3. In which position was the man who was most active as a leader in organizing your work?

   E____ C____ B____ D____ A____

4. Suppose you were to do these problems again with everything the same except that you could choose where you would sit. In which position would you choose to sit?

   A____ B____ D____ E____ C____

5. Suppose there were a very stupid person in your group and you could choose where to put him so that he would hurt the group record as little as possible. In which position would you put him?

   B____ A____ E____ C____ D____

6. If you wanted to sabotage the work of your group, in which position would you sit to do it?

   E____ D____ A____ C____ B____

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4. Genevieve O. Rogge, Technical Report No. 265, Research Laboratory of Electronics, M.I.T., 1952.

*These references are those specifically referred to in the text. Reference 1 contains an extensive bibliography of related material. For a comprehensive bibliography of information theory and cybernetics the reader is referred to: F. L. Stumpers, A bibliography of information theory, Research Laboratory of Electronics, M.I.T., 1953.