TECHNICAL INTERACTION AMONG ENGINEERS AND ITS RELATION TO PERFORMANCE

by

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Signature of Author . . . .
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Submitted to the Alfred P. Sloan School of Management in September, 1967, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

The objective of this study is to investigate the effects of technical interactions in R & D laboratories. The technical interactions are defined and limited to communications between colleagues on work-related matters. The National Aeronautics and Space Administration and the Department of Defense have been utilizing parallel projects during the early phases of large procurements. In order to control for differences in the nature of R & D tasks, the present investigation concerns itself with three sets of two teams each. Performance is evaluated by means of relative evaluations on three twin pairs of parallel problems consisting of many subproblems. The relative evaluations of parallel subproblems in R & D tasks are more precise and meaningful than absolute evaluations.

For each subproblem the engineer listed the colleagues whom he contacted during each week of the contract's duration. The engineer also indicated the frequency of interactions with each of these colleagues. A second measure of interaction was obtained by examining the duration of interactions with each colleague on each subproblem. Another index of the amount of colleague contact is the number and organizational position of the people with whom the engineer exchanges information. This question asks the man to indicate how many people he worked with during the previous week and categorizes these contacts on the basis of the contacted individuals' organizational position. In order to relate interaction to problem solving, the respondent was asked to estimate the probability of employing the alternatives under consideration for each subproblem.

To determine the impact of physical separation and floor plan configurations, forty respondents of one parallel laboratory and seventy-four respondents of the "twin" organization were administered a sociometric questionnaire. Each individual was asked to name those people in the organization with whom he most often discussed technical matters. The physical layout for both organizations was obtained by pacing off and drawing the relationships between the various sections.

Although the sections were close together physically, it was found that 87.5% of the choices for technical discussion occurred within one's own section. In the parallel organization, 86.9% of the choices for technical discussion occurred within one's own section. One may reason that the lack of interaction between sections is not so much a physical phenomenon as it is a result of the organizational structure. This structure was controlled for by studying individual sections. Inside the individual sections the technical discussion choices are almost exclusively neighbors. A further indication of the power of physical layout on technical discussion choices occurred when one section under examination was located in three separate rooms with doorways not more than ten yards apart. Colleagues strongly prefer to choose colleagues for technical discussion within the same room rather than leaving the room and going to an adjacent room. As a final measure of the relationship between those individuals selected for technical discussion and the physical arrangement, an integrated section spread out over some distance was examined. Once again, the number of technical discussion choices sharply drops off as the distance is increased.

In considering the effectiveness of interaction, it was found that there is a positive value to be derived from increasing the breadth of one's interactions. The results show a strong positive relationship between performance and interaction with members outside of the immediate group. The results concerning frequency and duration of interaction must be considered carefully. High performers were found to use more frequent interactions and spend more hours on interactions. The high performers also use more man-hours. When the interactions are examined per man-hour, there is no difference between the high and low performers. One may not conclude that for a given effort, increased interaction will lead to increased performance.

The relationship between interaction and the level of changes in probability among the alternatives was examined. Phase-lag correlations are used to determine the nature of the variation in correlations as a function of phase shift. The lowest correlations occur at zero shift with maximum correlations occurring several weeks before and after the maximum change in probability of alternatives. High interaction was found not to coincide but to both precede and follow large changes in probability of employing alternatives in the problem. By superimposing the interaction plots and the probability of alternatives, a model is developed that shows interaction serving the functions of refutation or development, as well as idea generation.

Professor William C. Greene
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Professor Greene:

In accordance with the requirements for graduation, I herewith submit a thesis entitled, "Technical Interaction Among Engineers and Its Relation to Performance."

Sincerely yours,

Arthur Gerstenfeld

ACKNOWLEDGMENTS

There are many people to whom I am indebted for helpful comments and criticisms during the preparation of this manuscript. I am particularly indebted to the members of my thesis committee: Professors Thomas J. Allen, Jr., Mason Haire, and Donald Marquis.

I sincerely appreciate the efforts of Professor Mason Haire who initially and during the course of the research offered suggestions and encouragement. I wish to also pay thanks to Donald Marquis for his continual advice and especially for his assistance with the research design. Tom Allen's rigorous research provided the bedrock for this current study. Professor Allen has not only been a good friend but has been a significant influence in my post-graduate career.

This study would not have been possible without the cooperation of the scientists and engineers of the organizations in this sample. They must remain anonymous, but I hereby express my appreciation for their many months of continual effort.

I would like to thank the National Aeronautical and Space Administration and the National Science Foundation for their financial support during the past two years.

To Carol Miller and Mary Bosco I express my gratitude for their editing and typing skills which were performed with speed, competence, and good humor.

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Chapter I

INTRODUCTION

The objective of this study is to investigate the effects of technical interactions in R & D laboratories. Interactions for purposes of this thesis are defined as communications between colleagues on work-related matters. The inquiry consists of several major aspects. The first aspect assesses the direct relationship between interaction and performance. The second aspect measures the effect of technical interaction on the problem-solving process. The third aspect examines the effects of physical distance on the choice of colleagues for technical interaction.

In order to control for differences in the nature of R&D tasks (without resorting to a large sample size), the present investigation uses matched pairs of parallel projects. The parallel projects provide an independent measure of performance since relative measures are generated.

The study of parallel projects has two major advantages over other approaches to the study of R & D. In the first place, the problem is controlled for technical substance. Many studies overcome this obstacle by using large sample sizes. By the use of parallel organizations working on the same problems, the sample size can be greatly decreased.

Secondly, comparative evaluations can be made between performances. The term "high" or "low" means different things to different people. The matched pairs permit the evaluator to rate one as "high" and the other as "low." This is done by breaking the contract into subproblems and evaluating separate matched pairs of subproblems.

During the parallel stage the contracts are small in dollar volume. Nevertheless, the incentive is high since the subsequent awards are sizable and often based on performance during these early periods. This policy of multiple contract awards provides a vehicle for the researcher interested in the study of research and development. Marquis and Allen originally developed the idea of employing this approach to the study of R & D.

Communication lies at the heart of the R & D process. It is becoming more and more difficult for engineers and scientists to communicate or learn the results of work performed elsewhere. As a result, the process of communication in R & D is a topic which has been receiving more and more consideration by social scientists.

Allen (1966) illustrates the degree to which sources of information within the laboratory organization can be of value to the engineer or scientist. He points out that although the internal channels suggest fewer ideas, those suggested have a greater probability of success.

Other studies (see for example, Schilling and Bernard, 1964) substantiate these results. It is the purpose of the present research to perform the next logical step forward. Recognizing the importance of internal sources of information, this study concerns itself with patterns of interaction and their relation to success, as well as the impact which physical layout has upon the structure of communication networks.

Specific Focus of the Study

One problem in answering questions about the amount of a man's interaction with his colleagues is to design a technique for measuring interaction. Since there is no obvious best way to accomplish this, the question is considered from several standpoints.[1]

First of all, the frequency with which a man contacts his colleagues during the course of work on a particular subproblem will be correlated with performance on that subproblem. Frequency of interaction is measured by asking

[1] "Colleagues" are defined for present purposes as other professionals with whom a man works within his laboratory organization.

the man, once a week, to indicate how frequently in the past week he communicated with each of his colleagues.

The second method of measuring interaction with colleagues is to ask, once a week, how much time was spent in this activity. The key question asks the man to indicate how much time was spent during the previous week communicating with colleagues.

Another index of the amount of colleague contact is the number of people with whom the scientist exchanges information. This question considers the scientist's immediate group as well as contacts elsewhere in the organization. The question asks the man to indicate how many people he worked with during the previous week and categorizes these contacts on the basis of the contacted individuals' organizational position.

Allen (1966) originated and used a device which he called the Solution Development Record. This instrument provides a record over time of the progress of an engineer toward the solution of a subproblem.

In using this device, the engineer provides a weekly estimate, for each alternative approach under consideration, of the probability that it will be finally chosen as the solution to his subproblem. The probabilities are plotted over time and related to the interaction network.

From the Solution Development Record plot and a record over time of the amount of interaction, one may observe the relation between the changes in probability of alternatives and the degree of interaction. Superimposing one plot on the other reveals phase relationships between the two measures.

Proposed Hypotheses and Evaluation Technique

The following hypotheses are based on theory and evidence from previous research data. There is evidence that increased interaction is related to higher individual performance (Pelz and Andrews, 1966). They examined interaction among members of a laboratory. They hypothesize that by interacting with one another, scientists can contribute to one another's effectiveness. Eight possible measures of communication with colleagues are examined. Four of these were found consistently related to interaction. Furthermore, colleague contacts were positively related to performance regardless of how the contacts originated. Even organization-initiated contacts seemed to enhance performance.

Many questions remain unanswered. One may ask about the phasing between individual effort and interaction. One may also attempt to determine whether a saturation point exists, for certainly beyond some threshold further interaction will add little.

Pelz used evaluations made by people in the same laboratory who knew the man's work and who felt qualified to compare it with the work of others in that laboratory. Judges were senior people from both the nonsupervisory and supervisory levels within each laboratory. Each judge provided two different rankings of the people he felt qualified to compare: first, according to their contribution to general technical or scientific knowledge in the field (within the past five years) and, second, according to their overall usefulness in helping the organization carry out its responsibilities (also within the past five years).

Judgments of individuals are influenced by halo effects and personal likings and dislikings. In addition, comparisons with each person in the laboratory will not tell whether the performance of the top man in one laboratory is above or below the performance of the top man in another laboratory.

Very often the number of scientific products, such as papers and patents, which the individual has produced is used as a performance criterion. This measure has two major difficulties. The first is that much development work does not result in published papers and patents and the second is that measuring the volume of papers does not in any way indicate their quality.

In the research performed in this thesis, evaluation is performed by outside government evaluators. It is true that the inherent disadvantage of judges still exists. They will be evaluating subproblem solutions instead of individuals. By evaluating each subproblem, the final product of the individual's efforts is considered rather than the person himself. A certain objectivity is thus gained since the influence of personal relationships is now removed.

Hypothesis 1

The increased interaction with technical personnel outside the immediate group but inside the organization will lead to more successful subproblem evaluations. This hypothesis is based on evidence which shows use of sources of information within the laboratory but outside of the immediate work group to be highly correlated with research success.

Hypothesis 2

Those subproblems that use more time spent in talking or other communication between colleagues in the same organization will receive more successful scores.

This hypothesis considers one aspect of interaction.

Each cooperating individual completes a form each week that provides information relating his interaction to a subproblem. This is compared with the government evaluation of that subproblem.

Hypothesis 3

Those subproblems will achieve more success where there is more frequent technical communication between colleagues.

Hypothesis 4

The change in the probability of alternatives (Δp) considered for a subproblem is directly related to the degree of interaction.

Hypothesis 5

Allen (1967) illustrates the effect in a laboratory of physical distance on sociometric choices. A pair of parallel organizations will now be considered by using a sociometric questionnaire and the physical layout. The hypothesis is that there is a strong negative relationship between the physical distance of separation and technical discussion choices.

Chapter II

RELEVANT THEORY AND RESEARCH

In the past several years a number of studies have examined the relationship between interaction and performance. Some of these studies present evidence that interaction contributes to the scientists' overall effectiveness. Other research, focusing in on specific components of the problem-solving process, shows the positive value of interaction during the evaluation phase. Several of these studies will now be discussed.

Taylor, Berry and Block (1958) show that interaction among group members restricts the formation of alternative solutions to problems. The study compares the performance of twelve groups whose members interacted with one another, and twelve groups whose members worked separately. Each group was made up of four persons and was instructed to generate as large a number of alternative solutions as possible within a fixed time limit. The results show that, for each of the three problems used, the non-interacting groups generated a larger number of different solutions and a larger number of high quality solutions than did the interacting group.

The next logical step was to replicate these findings in a more realistic field setting. Dunnette, Campbell and Jaastad (1963), using industrial employees as subjects, performed this replication. The results are highly consistent with those obtained by Taylor et al. They add further support to the idea that group interaction inhibits the generation of alternative solutions to the problem.

On the other hand, interaction may be helpful when the phase of problem solving involves the evaluation rather than the generation of alternative solutions. Timmons (1942) had subjects rank order five possible options to a parole system. On the basis of these rankings two groups were constructed with members of each matched on the basis of initial rankings. One set of groups discussed the alternatives as a group and obtained a group ranking for the alternatives. The other groups restudied the problem as individuals and re-ranked the alternatives without discussion.

Using expert judgment of the five alternatives as a criterion, scores were obtained for the groups. The mean improvement in scores of the interacting groups was found to significantly exceed the mean improvement in scores of the nondiscussion groups. This demonstrates the positive contribution which interaction can make during the evaluative phase of problem solving.

Vroom (1966) sums up the functional and dysfunctional effects of interaction during the various phases of the problem-solving process:

> "There is some evidence that interaction among individuals is dysfunctional during the creative phase of problem solving in which alternative solutions are being generated but may be functional during the evaluative phase in which solutions are screened and chosen."

Interaction Affected by Communication Networks

Following the original work by Bavelas (1948), many experiments have compared the effectiveness of different communication networks as shown in Figure 2-1.

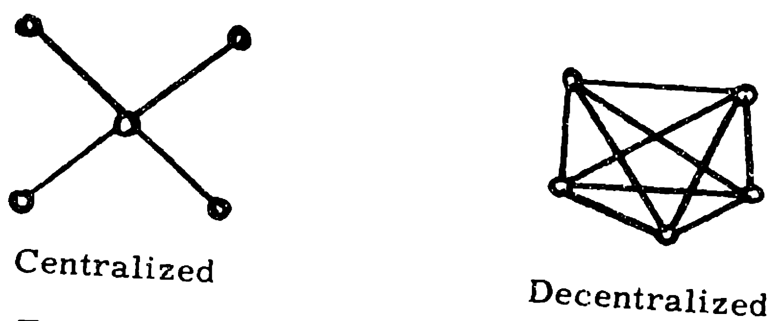


Fig. 2-1. Centralized and decentralized communication networks.

Using five-man networks on simple problems, a number of investigators (Leavitt, 1951; Morrissette, Switzer, and Crannell, 1965; Cohen, Bennis, and Wolkin, 1961; Guetzkow and Simon, 1955; Mohanna and Argyle, 1960) have found that centralized structures are more efficient, as measured by speed of attaining solutions, than are decentralized structures.

The results of other experiments suggest that the differences between centralized and decentralized structures vary with the kind of task. Shaw (1954) finds that a communication pattern which places one person in a central position requires more time to solve relatively complex problems but less time to solve relatively simple problems.

As the complexity of the problem increases, the possibility of contributions from all members of the group becomes much more important. This is true because partial solutions can be delegated to various positions. With complex problems, the centralized structure should be slower than the decentralized because the central person becomes saturated (i.e., because he must do most of the work of the actual solution). In his theoretical explanation, Shaw suggests that the differences found between the structures are due to the "availability of information" (with regard to simple problems) and to the "possibility of contributions" from all members of the group (complex problems).

Muldner (1960) finds that the more centralized the decision structure of groups, the better the group's performance in terms of speed, quality and efficiency.

The implication is that no single network is most efficient for all tasks. Decentralized structures have an advantage for tasks which are difficult, complex or unusual, while centralized structures are more effective for those which are simple and highly routinized. In the present research, the R & D tasks are complex. Based on the above studies, the laboratory manager should therefore be encouraged to use a decentralized structure.

Two-Step Flow of Information

Lazarsfeld, Berelson and Gaudet (1944) find that personal interaction is much effective than the mass media in inducing changes in voting decisions. Between two-thirds and three-fourths of the voters in the United States vote for the same party that their fathers voted for. However, one may argue that it is not so much the personal interaction as it is the fact that the parents and children generally belong to the same social class and religious groups.

To consider that question further, Berelson, Lazarsfeld and McPhee (1954) studied the voting behavior in Elmira, New York during the 1948 election campaign. They find that the votes of persons whose social-class position conflicted with their family background is as often determined by the family group as by the larger social-class group. The studies suggest the greater effectiveness of personal interaction due to the increased flexibility of face-to-face persuasion.

Katz and Lazarsfeld (1955) compare the relative impact of personal influence and mass media on such personal decisions as the purchase of food and other household goods, the choice of motion pictures, and fashion changes. In all three types of decisions, personal influence plays a greater role than any of the mass media.

In Figure 2-2 personal interaction is compared with other information sources in terms of impact on buyer behavior. "Effective exposure" refers to persons who mention a given influence, indicate that it played a specific role (e.g., taught them something or directed them toward something), and further state that it was the most important factor in their decision. The heights of the bar graphs in Figure 2-2 are the ratio of "effective exposure" to a particular medium to total exposure to that medium.

The greater effectiveness of face-to-face influence does not mean that the mass media are not important. Katz and Lazarsfeld describe the process of information flow from the mass media as a two-step process:

> "Ideas often flow from radio and print to the opinion leaders and from them to the less active sections of the population."

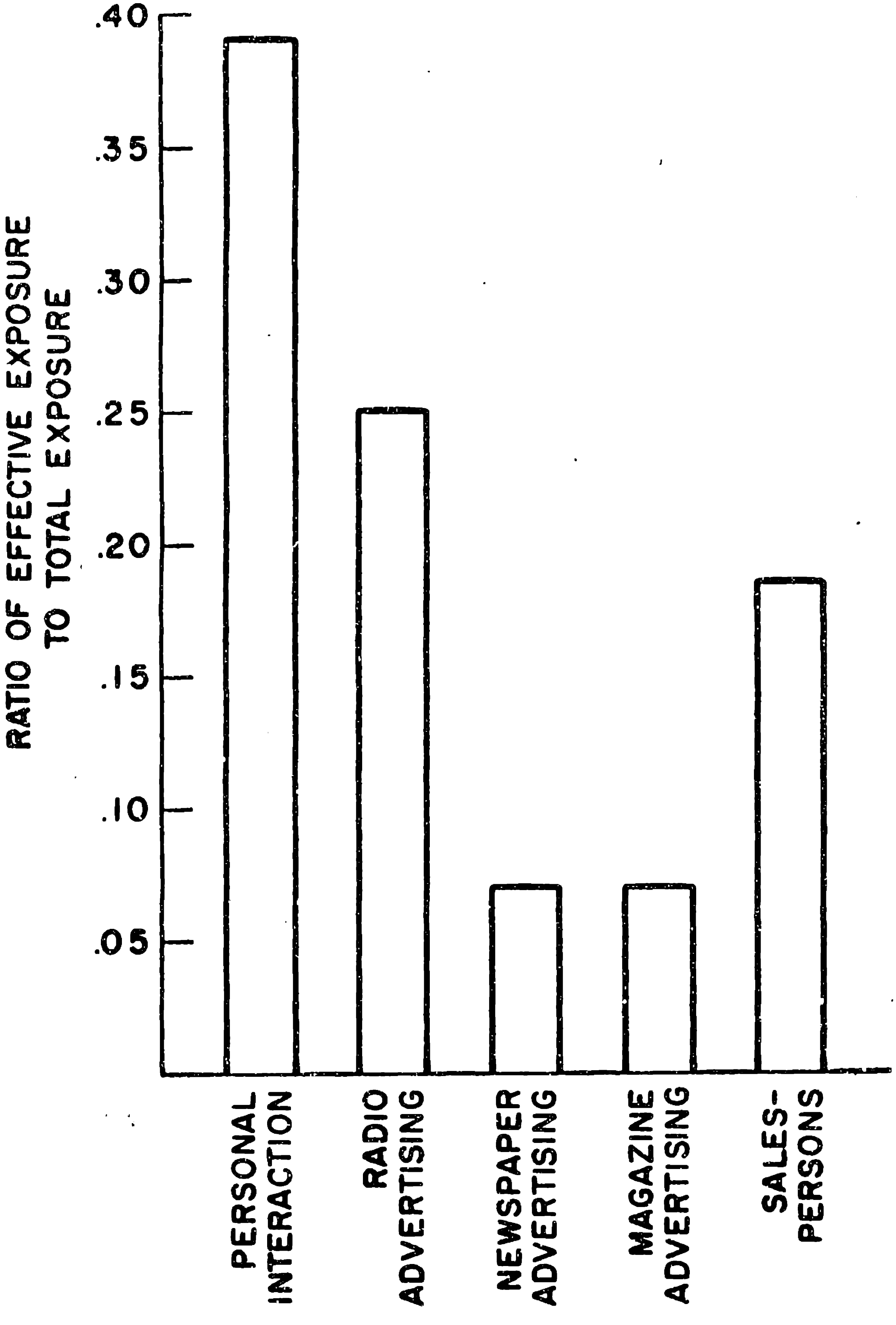


FIGURE 2-2 RELATIVE EFFECTIVENESS OF INTERACTION AND OTHER INFORMATION SOURCES ON MARKETING SHIFTS (KATZ AND LAZARSFELD, 1955)

Menzel and Katz (1955) consider a closed community of specialists to study the two-step flow of communication. The investigators interviewed 33 of the 40 doctors practicing in a New England city of approximately 30,000.

Table 2-1

Drug-Talk Choices and Channels Employed in Decisions on Two Recent Drug Adoptions (Menzel and Katz, 1955)

#	Description	Drug-talk choices received (by percentage)		
		No Sociometric Choices	One and Two Sociometric Choices	Three or More Sociometric Choices
1	Mail and periodicals	30	18	21
2	Journal articles	10	39	32
3	Detail men	40	25	21
4	Colleagues	15	15	16
5	Meetings	0	0	11
6	Other channels	5	3	0

Table 2-1 shows that journal reading plays a much larger role in the drug adoptions of doctors who receive one or more designations than among the isolates. In other words, while the majority of doctors do not read the journals, some do, and the few that do are also at the center of social activities in the community. This enables them to easily pass along to their colleagues information that they gain from journal reading. Only those who receive three choices or more report that what they learned at meetings entered into their decisions. The sociometric star does seem to serve as a relay. He incorporates what he has learned at the meetings into his own decisions and into his conversations with others.

Allen and Cohen (1966) find substantial support for the role of technological gatekeepers. These are people to whom others turn for technical discussion and consultation and who report having a greater amount of contact with the professional and scientific literature or with technically trained friends outside the laboratory. The people who were responsible for introducing the most important ideas were people who were above average in their use of the literature and of interpersonal contacts outside of the organization as sources of technical information.

Interaction and Effectiveness

Pelz and Andrews (1966) hypothesized that interaction would contribute to the scientists' effectiveness. Some of their performance data are based on judgments of each man's work. These judgments are made by people in the same laboratory who know the man's work and who feel qualified to compare it with the work of others in that laboratory. Judges were senior people from both the nonsupervisory and supervisory levels within each laboratory. Performance was also evaluated objectively: the number of scientific papers an individual had published, the number of patents or patent applications, and the number of unpublished technical manuscripts.

The data on which the study is based came from 1,311 scientists and engineers located in eleven different laboratories. The categories are as follows:

641 professionals in five industrial laboratories

144 professors from seven academic departments

526 scientists and engineers from five government laboratories

The results show that among Ph.D.'s in development or research laboratories and engineers, high performers contact their colleagues with above-average frequency. For Ph.D.'s in development laboratories, the optimum frequency is daily for three of the four performance measures. For Ph.D.'s in research, performance is better with semi-weekly or daily contact than with lower frequencies. For engineers, the optimum frequency is semi-weekly for most measures of performance.

Relationships are examined between scientists' performance and the number of people they exchanged information with outside of their own group (but within their organization). The general finding is that high performance is shown by the scientists who had high amounts of colleague contact. Conversely, scientists who exchanged information with very few people outside their own groups tend to have low performance.

Roberts (1965) shows that the award of research and development contracts is a case primarily of person-to-person contact. From both the government data and the industry evidence, the conclusion points to the crucial need for informal person-to-person contacts in research and development marketing.

Chapter III

RESEARCH METHODS

Performance is evaluated in this study by means of relative evaluations of twin pairs of parallel problems or subproblems. The use of parallel identical pairs of subproblems controls for variation in the nature of the work being performed (compares the behaviors of individuals working on the same problems) and enables us to obtain relative evaluations of solutions to the same problems. Relative evaluations are much easier to make in this sort of situation and are probably far more precise and meaningful than absolute evaluations.

Parallel Projects

The National Aeronautics and Space Administration and the Department of Defense have been utilizing parallel projects during the early phases of large procurements. The motivation is twofold: the design concepts of more than one team are considered in an early phase, while costs are still reasonably low, and the more favorable team is oftentimes given the opportunity to continue with the design. In many cases, more than two teams are involved, although this particular study concerns itself with three sets of two teams each.

Longitudinal Data Collection (Interaction Development Record)

An example of an interaction development record is presented in Figure 3-1. The names of each individual's principal colleagues are listed on the left-hand side. Then, to simplify the reporting procedure, he circles the number that most closely represents the number of times in the past week that he communicated with that colleague.

Listing each colleague separately increases the accuracy of the score. If the respondent were merely asked to indicate the aggregate number of interactions, it would be a figure of doubtful validity. After the first few weeks many individuals kept private records for themselves as interactions took place. This further decreased any error that might be attributable to memory.

Measuring the frequency of interaction leaves open the question of how long each interaction took. In other words, why should a three-hour meeting be counted the same as a half-hour meeting? The objection is certainly valid and leads to the second question on Figure 3-1.

In this case, as in the previous one, the name of each colleague is listed on the left-hand side. The respondent is then asked each week to indicate the number of hours that he spent in discourse with that individual.

M. I. T.
Interaction Development Record

Company ___Reactor Corporation___

Contract Name ___Post Flight Analysis___

Individual
Name ___P. Robinson___

Subproblem ___α___

Date ___May 12, 1967___

1. On the above referenced subproblem please indicate by circling the appropriate numbers how frequently in the past week you communicated with each of your colleagues on work-related matters. (Whether by conversation, memos, seminars, etc.)

Name of Colleague	Number of times per week											Other
	0	1	2	3	4	5	6	7	8	9	10	
R. Smith	0	1	2	3	4	5	6	7	(8)	9	10	____
B. Jones	0	1	(2)	3	4	5	6	7	8	9	10	____
A. White	0	(1)	2	3	4	5	6	7	8	9	10	____
W. Burke	0	(1)	2	3	4	5	6	7	8	9	10	____
____	0	1	2	3	4	5	6	7	8	9	10	____
____	0	1	2	3	4	5	6	7	8	9	10	____
____	0	1	2	3	4	5	6	7	8	9	10	____

2. On the above referenced subproblem please indicate by circling the appropriate numbers about how much time was spent in the past week talking or communicating with your colleagues regarding the problem.

Name of Colleague	Number of hours per week											Other
	0	1	2	3	4	5	6	7	8	9	10	
R. Smith	0	1	2	3	(4)	5	6	7	8	9	10	____
B. Jones	0	1	(2)	3	4	5	6	7	8	9	10	____
A. White	0	(1)	2	3	4	5	6	7	8	9	10	____
W. Burke	0	(1)	2	3	4	5	6	7	8	9	10	____
____	0	1	2	3	4	5	6	7	8	9	10	____
____	0	1	2	3	4	5	6	7	8	9	10	____
____	0	1	2	3	4	5	6	7	8	9	10	____

"Colleagues" are defined for these purposes as all professional associates who contribute, technically, to the solution of the subproblem.

Fig. 3-1. Interaction Development Record (frequency and duration of interactions). (The data is from an actual example with codes in place of the real names.)

In part 3 of the form (Figure 3-2), the respondent indicates the number of people with whom he worked for each subproblem that he reports on. He has the categories of vendor, customer, external source, and two categories of technical staff, TS1 and TS2,(defined in Table 3-1) to indicate accordingly.

For ease of use, each category has a series of numbers, one of which may be circled. In addition, a column for "Other" is presented in the event that the number exceeds 10 in any one category for any one week.

In Figure 3-2, Question 4 establishes a pattern for the consideration of alternatives during the course of the project. On the left-hand side a series of alternatives is listed.

An example from the research is as follows:

Alternatives Under Consideration

Specific Ion El.
Photometry
Electron Probe
X-Ray Fluorescence
Coulometry

As described by Allen (1966), the respondent estimates a probability that a given alternative will be employed. All alternatives are listed, even though on some particular week a given alternative may be given a zero probability of being the final choice.

3. On the above referenced subproblem please indicate by circling the appropriate numbers how many people you worked with in the past week.

	Number of people worked with											Other
Vendor	**(0)**	1	2	3	4	5	6	7	8	9	10	______
Customer	**(0)**	1	2	3	4	5	6	7	8	9	10	______
External Source	0	**(1)**	2	3	4	5	6	7	8	9	10	______
Technical Staff 1	0	1	**(2)**	3	4	5	6	7	8	9	10	______
Technical Staff 2	0	1	**(2)**	3	4	5	6	7	8	9	10	______

4. Estimate of probability that a given alternative will be employed. (Please circle a probability estimate for each alternative.)

Alternatives under Consideration											
Specific Ion El.	0	.1	.2	**(.3)**	.4	.5	.6	.7	.8	.9	1.0
Photometry	0	.1	.2	.3	.4	**(.5)**	.6	.7	.8	.9	1.0
Electron Probe	0	**(.1)**	.2	.3	.4	.5	.6	.7	.8	.9	1.0
X-Ray Fluor.	0	**(.1)**	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Coulometry	**(0)**	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

(Circled probabilities should add to one.)

5. __25__ % of total time was spent on this subproblem, this week.

Thank you!

Fig. 3-2. Interaction Development Record (source matrix and probabilities). (Data shown as received.)

Table 3-1

Information Sources

V = vendors:	representatives of, or documentation generated by, suppliers or potential suppliers of design components.
C = customer:	representatives of, or documentation generated by, the government agency for which the project is performed.
ES = external sources:	sources outside the laboratory which do not fall into either of the above two categories. These include paid and unpaid consultants and representatives of government agencies other than the customer agency.
TS1 = technical staff:	engineers and scientists in the laboratory who are not assigned directly to the project being considered but are members of your own functional group.
TS2 = technical staff:	engineers and scientists in the laboratory who are not assigned directly to the project being considered and are not members of your functional group.

In the example shown previously, the specific ion, el. was given a probability of 0.3, photometry was given 0.5, electron probe given 0.1, X-ray fluorescence given 0.1, and coulometry zero. The circled probabilities should add to one.

During the course of the project, new alternatives may appear and others approach one. At project completion when an alternative is adopted, that alternative receives a score of one and all of the others should go to zero.

Over the course of the project, the Interaction Development Record is mailed weekly to each respondent. The names of the colleagues are typed in by this researcher so that the respondent merely has to circle the appropriate numbers. This is done not only as a service to the cooperating organization but serves as a reminder of all colleagues with whom the respondent may have interacted. If the respondent were given the task of entering the names, then some people might be forgotten. If all the names are listed in advance, then the absence of interaction with a particular person on a given week can just be indicated by circling the zero next to that colleague's name.

Follow-Up Interviews

At project completion each of the participants is presented the data showing both the interaction graphs and the alternative selections. There are two major reasons for this procedure. The accumulated data are checked to see that the facts are indeed as they seem to be. Secondly, impressions, explanations, and ideas triggered as a result of observing the data can be gathered at this time.

The sociometric questionnaires are administered to a larger group than those involved with the particular project. They are completed immediately since they only involve a single page and three questions.

At this point, a physical layout of the research facility is obtained that indicates the location of each of the R & D personnel. In those cases where floor plans are not available, or are not up to date, this researcher noted the various locations and paced the separation between individuals, particularly noting the location of doors and aisles.

The government technical monitors are asked at project completion to evaluate each set of the solutions to parallel subproblems. The subproblem approach is utilized since overall contract performance is contaminated with many other factors. The evaluations are performed during a final interview and after the teams have presented to the technical monitors both written and oral reports of their performance. The ratings were performed on an ordinal scale and the evaluators indicated "high" or "low" performance.

Units of Analysis

Interaction is measured in terms of both frequency and duration. The units of measurement for frequency are the summation of "number of times per week" (Question 1 in Figure 3-1).

As an example, refer to Figure 3-1 on page 3-3. For that particular week the interaction in terms of frequency is as follows:

Colleague			Number of Times
R. Smith	=		8
B. Jones	=		2
A. White	=		1
W. Burke	=		1
		Total	12 times

(P. Robinson met with colleagues regarding subproblem α a total of 12 times for that particular week.)

Referring again to Figure 3-1, the interaction pattern in terms of duration is as follows:

Colleague			Number of Hours
R. Smith	=		4
B. Jones	=		2
A. White	=		1
W. Burke	=		1
		Total	8 hours

(P. Robinson met with colleagues regarding subproblem α a total of 8 hours for that particular week.)

The numbers represent the aggregate duration of interactions that occurred during the week ending on a particular date.

The data from Question 4 in Figure 3-2 provide the basis for the plots of probability of alternatives over time. This has already been described, and it only remains to indicate the method proposed for relating this solution development record to the interaction analysis. By plotting the probability of alternatives over time on clear paper with the same horizontal time base, it will be possible to observe the changing of alternatives in relation to the interaction pattern.

Organizations

The companies involved in this study are either in the general field of aerospace development or microbiology. The first company considered is a large, multi-faceted organization with this project being performed in its aerospace division. Microbiology work, which makes up a large portion of the present project, is performed by a small subgroup within this division.

Their "twin" is a smaller organization which is entirely devoted to space research. Since the capabilities of this organization were limited regarding biological skills, they subcontracted much of the effort to a large biological laboratory. The subcontractor in this case agreed to participate in the study, so that essentially — although it is second tier — the two "twin" groups are of comparable size.

The second pair of organizations consists of one organization primarily concerned with aircraft overhaul and the second a smaller, space-oriented organization that subcontracted the large part of the effort to a larger biological laboratory. In this case, the information is again obtained from the subcontractor.

The third set consists of a large computer manufacturer and a large space laboratory. In this case, the space laboratory and the computer manufacturer both have the in-house capabilities for microbiological studies.

R & D Under Study

The work under study may be placed on a continuum midway between basic research and development. The R & D studies are directed and strive toward a result that surely moves it away from the area of basic research. However, there is no end product and the development is to be performed at a later stage.

An example from one of the contracts might best illustrate this point. This study is concerned with man's physiological response to space flight. The task is to develop methodologies for use during flight that will permit analyses to be performed on blood, urine, sweat, saliva, and feces in a zero gravity environment. The physical methods of analyses should lend themselves to use in flight where sample preparation, astronaut training and participation are minimal.

The program was intended to establish the feasibility of developing X-ray, electrical and other suitable physical methods for analyses of biological samples under conditions of space flight (weightlessness, and weight, volume and power constraints).

Government as Customer

Each of these parallel contracts has a government agency as the customer. This affords the advantage of the two competitors starting at approximately the same time. Furthermore, the fixed sum of money and fixed completion dates aid in making the environment of the "twins" more alike.

Chapter IV

TECHNICAL INTERACTION AMONG COLLEAGUES AND ITS RELATION TO PERFORMANCE

It is believed by many engineers and laboratory managers that technical interaction is positively related to performance. This research examines that question from several viewpoints. Hypothesis 1 states that interaction with a greater number of technical personnel outside of the immediate project group but within the organization will result in higher quality research. The breadth of interaction is considered as the number of colleagues with whom one interacts. In other words, the breadth of a man's contacts with colleagues will be directly related to the quality of his research. The following are three categories of technical staff with whom a project member may interact:

1) TS0: Engineers and scientists in the laboratory who are assigned directly to the same project.

2) TS1: Engineers and scientists in the laboratory who are <u>not</u> assigned directly to the project being considered but are members of the <u>same</u> functional group as the project member with whom contact is made.

3) TS2: Engineers and scientists in the laboratory who are not assigned directly to the project being

considered and who are not members of the same functional group.

No relation is found between TS0 and performance. The implication is that increased interaction within the closely assigned group will not improve performance.

Table 4-1 shows the total number of colleagues in category TS1 with whom project members worked each week. On nearly all subproblems, the higher performers interacted with a greater number of colleagues within their own functional group. The relationship over all subproblems is statistically significant.

Table 4-2 shows a significantly positive relationship between contacts with colleagues in category TS2 and subproblem evaluation. Among the low performers there was little or no contact with colleagues outside of the functional group.

Contacts with all colleagues beyond the immediate project group are aggregated in Table 4-3. Interaction with a greater number of colleagues is positively related to research performance. This confirms Hypothesis 1. The problem solver should be strongly encouraged to broaden his horizons and increase the number of people with whom he has contact outside of his immediate project group.

These findings are in accord with Pelz and Andrews'

Table 4-1

Total Number of Colleagues Worked With
Per Week in Category TS1

Subproblem	High Performance	Low Performance
a	4	0
b	8	0
c	42	1
d	5	2
e	5	2
f	4	3
g	4	5
h	8	0

$t = 1.39$
$.05 < p < .10$

Table 4-2

Total Number of Colleagues Worked With
Per Week in Category TS2

Subproblem	High Performance	Low Performance
a	4	0
b	7	0
c	0	0
d	5	0
e	5	1
f	0	0
g	0	0
h	5	0

$t = 1.97$
$.025 < p < .05$

Table 4-3

Total Number of Colleagues Worked With Per Week in Categories TS1 and TS2

Subproblem	High Performance	Low Performance
a	8	0
b	15	0
c	42	1
d	10	2
e	10	3
f	4	3
g	4	5
h	13	0

$t = 1.72$
$.025 < p < .05$

(1966) results which they summarize as follows:

> Furthermore, we found that frequent contacts with many colleagues seemed more beneficial than frequent contact with just a few colleagues. Similarly, having many colleagues both inside and outside of one's own group seemed better than having many colleagues in one place and just a few in the other. So anything you can do to promote these forms of contact should be in the right direction.

Interaction Measured By Duration

Hypothesis 2 states that those individuals who spend more time in communication with colleagues will perform more successfully on their research tasks. The total number of hours spent on each subproblem by high and low performers is shown in Table 4-4.

Table 4-4

Total Interaction Measured by Duration in Hours

Subproblem	High Performance	Low Performance
a	54	4
b	60	15
c	139	76
d	60	31
e	48	14
f	58	10
g	51	13
h	50	14

$F = 10.1$
$p = .01$

High and low performers spend significantly different amounts of time in interaction. Those researchers who interact more with their colleagues produce the more highly evaluated subproblem solutions.

However, a word of caution should be injected at this point. One may correctly argue that a greater amount of total interaction results in higher quality research simply because more total effort is allocated to the problem. In other words, it is not so much the increased interaction but the fact that all problem-related activities are increased that produces the high quality solution. Following this thinking a step further, let us consider the converse. Those subproblems in which individuals report low interaction receive low ratings not so much because of the small amount of interaction, but because they spent less total effort on the subproblem. Subproblems in which more man-hours were spent were rated significantly higher than those on which the researchers spent less time.

Indeed, the argument has merit, so we must control for the total amount of time that is utilized on each subproblem. One can again try to compare the number of man-hours devoted to interactions by high and low performers. The relationship now disappears. Hypothesis 2 is therefore unsupported by the evidence.

Frequency of Interaction

Hypothesis 3 states that on those subproblems in which communication among colleagues is more frequent, a greater degree of success will be achieved. Table 4-5 shows the frequency or number of interactions by both high and low performers.

The results shown in Table 4-5 clearly resemble those in Table 4-4. Pelz and Andrews (1966) report similar results:

> This measure (time) proved to be highly related to the first one on frequency of contact. On the whole, scientists who spent a good deal of time seeing colleagues tended to see them frequently (that is, long, infrequent meetings were unusual), and those who spent little time tended to see their colleagues only rarely. Since the measures were highly related, it was not surprising to find that the relationships with performance were also similar.

Table 4-5

Total Interaction Measured by Frequency

Subproblem	High Performance	Low Performance
a	107	8
b	143	45
c	407	112
d	80	17
e	146	12
f	85	8
g	58	31
h	98	20

$F = 6.91$
$p = .02$

The initial reaction is to again conclude that there is a significant difference between the frequency of interaction associated with high and low performance. The same criticism that was raised in the previous section should again be considered. Surely, those subproblems on which a greater number of man-hours is expended result in a greater frequency of contacts. Nevertheless, when the frequency of contact is normalized with respect to total man-hours, the once significant relationship again disappears.

One may only conclude, regarding Hypothesis 3, that there is a relationship between frequency of interaction and performance but it could well be due to additional effort rather than additional interaction. One may not conclude that for a given time allocation, increased frequency of interaction will lead to improved performance.

Interaction in Perspective

Hypothesis 1 proposes the value to be derived from increasing the breadth of one's interactions. The results confirm this hypothesis, showing a strong positive relationship between performance and interaction with members outside of the immediate group.

Hypotheses 2 and 3 propose that interactions measured by frequency and duration are positively related to performance. The results concerning these hypotheses must be examined carefully. It is true that high performers use more frequent interactions and spend more hours on interactions. The high performers also use more man-hours. When the interactions are examined per man-hour, there is no difference between the high and low performers. One may not conclude that for a given effort, increased interaction will lead to increased performance.

The results can best be summed up in the following manner. Increased interaction is desirable and should be encouraged. The major emphasis should, however, be placed on selecting the proper people with whom to communicate, rather than on merely increasing the amount of communication. Anything that can be done to encourage engineers to increase the breadth of their interaction is desirable. Teams, committees, seminars, and evaluation groups are all possible techniques. Moreover, the men working in related areas must be made aware of each other's activities, interests, and problems. A climate of mutual helpfulness and support must be the goal.

Chapter V

EFFECTS OF INTERACTION ON ESTIMATED PROBABILITY OF ADOPTION OF ALTERNATIVES

If interaction is employed to generate information regarding the nature of the problem itself or any of the solution alternatives, then this relation should be seen in the time plots of Solution Development Records and reported interaction. One would expect that if this were the case, reports of high interaction would either coincide with or slightly precede changes in the probability level of alternatives. On the other hand, if interaction is used to check out or confirm information gathered from other sources, then it would be expected that interaction reports would lag somewhat behind changes in probability.

Lag Correlations

Figure 5-1 examines the relationships between interaction and the level of changes in probability among the alternatives (Δp) using the data from the seven subproblems that had mutually exclusive alternatives. Phase lag correlations are used to determine the nature of the variation in correlations as a function of phase shift. As seen in

Figure 5-1, the lowest correlations occur at zero shift with maximum correlations occurring several weeks before and after the maximum change in probability of alternatives. In other words, with zero phase shift, changes in probability (Δp) occur at different points of time than does interaction. Shifting phase of the two plots either forward or backward brings about a higher correlation between the two. This demonstrates the phase relation between the two phenomena. Interaction both precedes and follows probability changes by a week or two.

The Relationship Between Interaction and Solution Development

Information obtained through interaction results, after a one- or two-week lag, in changes in the probabilities of acceptance assigned to the various alternatives under consideration. Support and confirmation for these changes are then sought by once again interacting with colleagues.

Leavitt (1951) found that a completion of the circuit between sender and receiver increases the accuracy with which information is transmitted. This type of interaction increases the receiver and sender confidence in what they accomplished. By interacting, an individual can receive feedback on the way he is moving toward a solution.

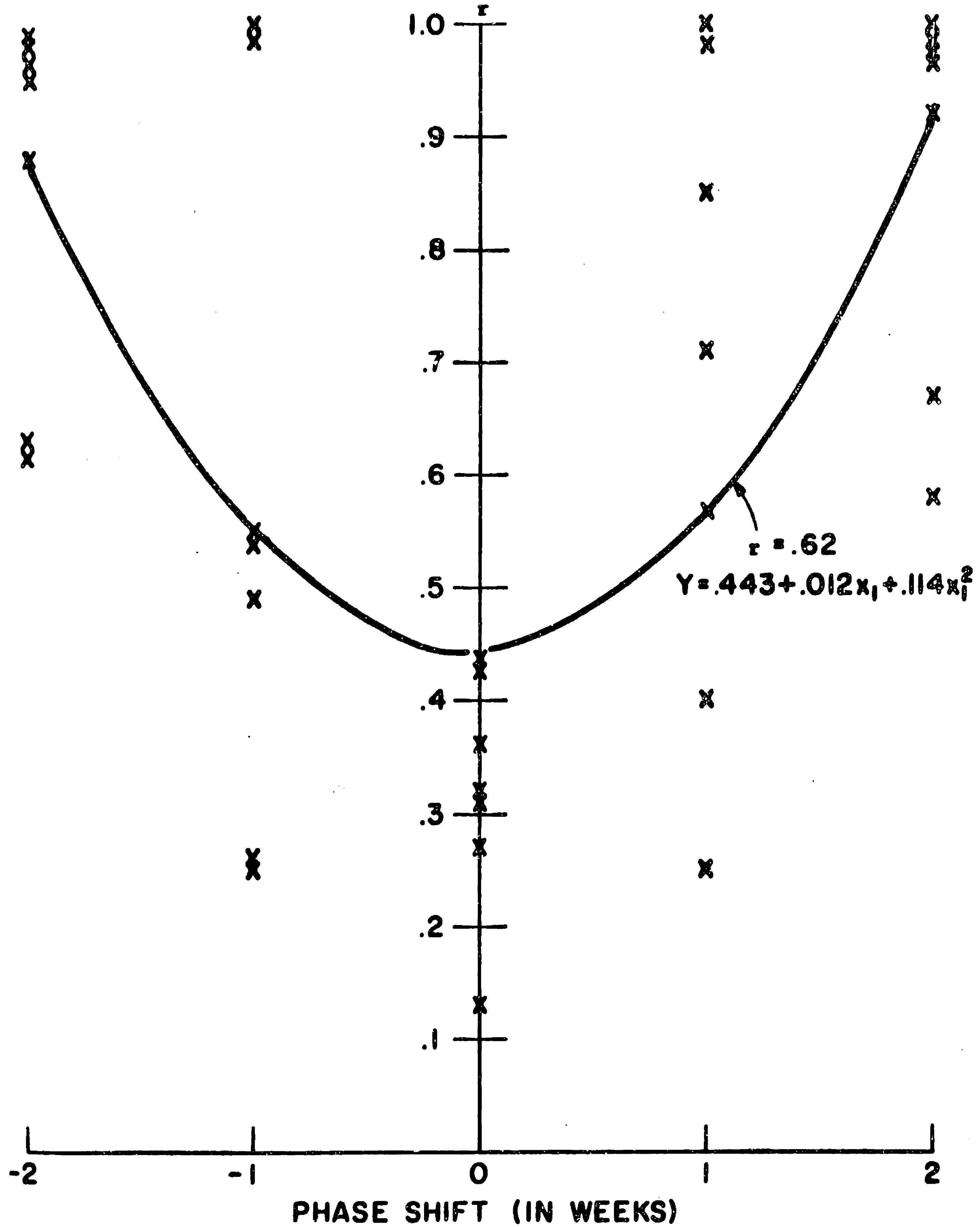
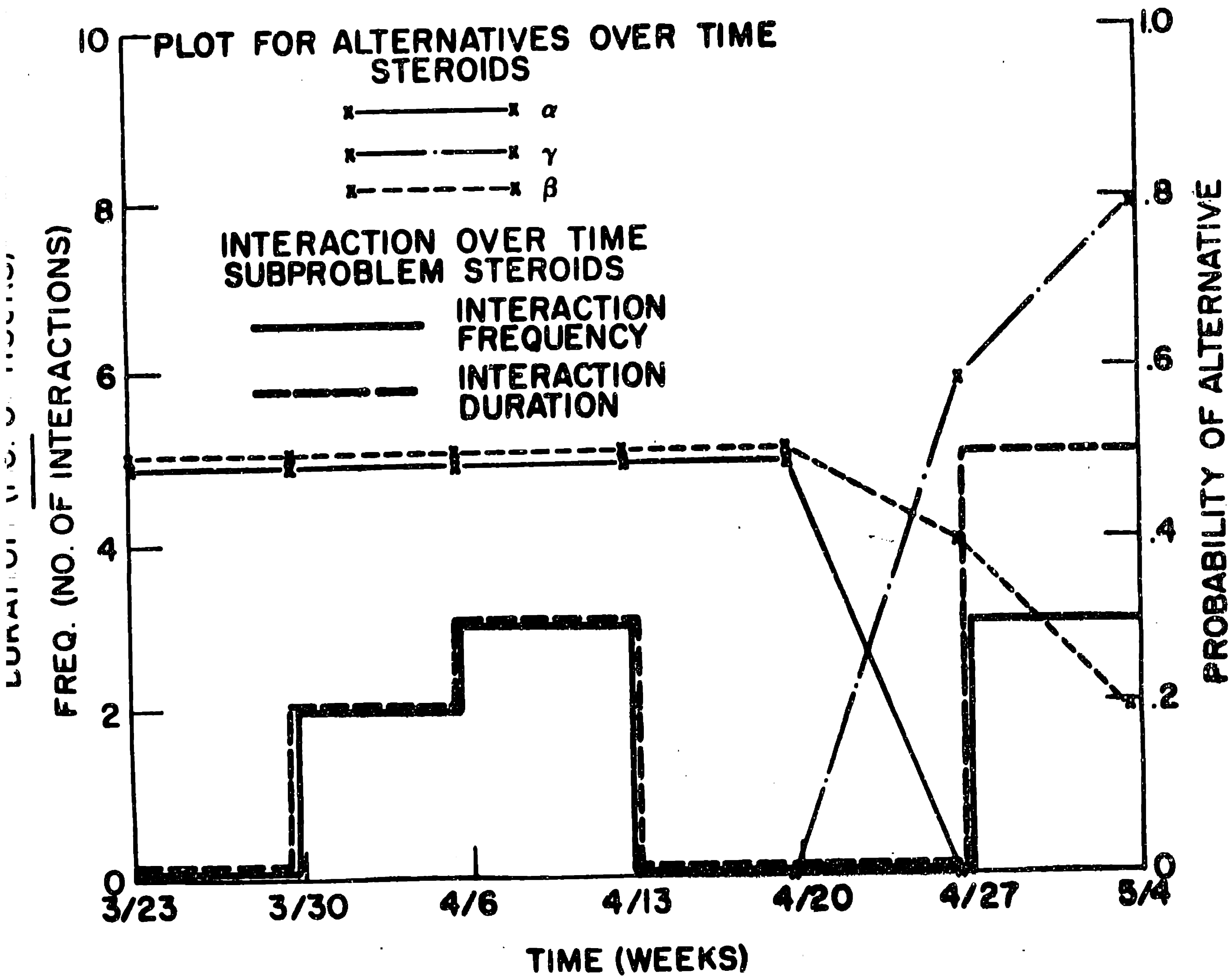


FIGURE 5-1 PLOT OF CORRELATION BETWEEN INTERACTION

I would like to argue that the new ideas enter and probability changes occur during a complex cycle. Interaction is followed by independent effort which is in turn followed by interaction. Figure 5-2 provides an example of this. This is one of the subproblems reported on by Laboratory B and is typical of the situation found for the seven subproblems (see Appendix).

Initially, in this problem, there was a probability = 0.5 for α and a probability = 0.5 for β. Between the fifth and sixth reports, the alternative γ entered and by April 27 this probability had a 0.6 chance of being the recommended method.

Superimposing the reported interaction levels on the probability plots shows that, in general, the change in probabilities of alternatives occurs between peaks in the interaction plots. In a post-project interview, one scientist described how this occurred. He first discovered the isotope dilution process (γ) in the literature and afterward "tried the idea out on his colleagues." It is the contention of this thesis that this is a common problem-solving technique and that very frequently interaction serves the functions of refutation or development, as well as idea generation.


PLOT FOR ALTERNATIVES OVER TIME
STEROIDS
α
γ
β
INTERACTION OVER TIME
SUBPROBLEM STEROIDS
INTERACTION FREQUENCY
INTERACTION DURATION
FREQ. (NO. OF INTERACTIONS)
PROBABILITY OF ALTERNATIVE
10
8
6
4
2
0
1.0
.8
.6
.4
.2
0
3/23
3/30
4/6
4/13
4/20
4/27
5/4
TIME (WEEKS)

The Cycle Model

It is time to start developing a new model of the problem-solving process. I will first review some of the previous research and from that point move on to the present hypothesis.

As has been shown in the studies by Gordon (1924), Stroop (1932), and Preston (1938), validity is enhanced by pooling judgments. The greater the number of competent judges, the greater the validity of their combined judgments. Groups have an advantage over individuals when the task situation is one in which each group member is making the same kind of judgment about the same event.

Perlmutter and de Montmollin (1952) present evidence that "group learning" is superior to that of individuals. Twenty groups of three persons each were required to learn two equivalent lists of nonsense words. One list was learned while each person worked individually but in the presence of the other two. The other list was learned while the three persons worked together as a group. The results reveal that on all five trials, the average group recalled more words correctly than did the average individual. In fact, the group recall scores tended to be equal to or better than the best individual scores.

Shaw (1932) presents further evidence indicating the superior quality of group solutions, which leads to my hypothesis. Individuals and groups of four worked on a number of problems. When compared on speed of performance, the data were inconsistent; but that was not the case when compared on accuracy. The groups produced a substantially greater percentage of correct solutions to the problems. Observation of the group process revealed on one problem that although twice as many correct as incorrect suggestions were made, the groups rejected five times as many incorrect as correct suggestions. Furthermore, and this leads directly into my model, the initiator rejected only one-third as many of his own incorrect suggestions as did other members of the group. Shaw comments: " . . . . one point of group supremacy is the rejection of incorrect ideas that escape the notice of the individual when working alone."

Davis and Restle (1963) find that the probability of a correct solution is higher for groups than for individuals. Nevertheless, this greater probability of success is not achieved without a higher investment in man hours.

Vroom (1966) points out that he would expect similar results in actual organizational situations. The evidence suggests that allocating problem-solving tasks to work groups requires a greater investment of man hours but produces a higher chance of success.

Referring to the various graphs where the alternatives are overlays for the graphs on interactions, several different explanations start to emerge. Let us now reconsider Figure 5-2.

For a period of four weeks there are two alternatives that are considered equally. During those four weeks, interaction builds up when measured both in terms of frequency and in terms of duration. Nevertheless, the alternatives do not change.

The violent change which takes place during the fifth week could have resulted from the interactions that occurred earlier. This could be explained in terms of Soelberg's (1966) thesis that the decision to drop the two dominant alternatives was made during the interaction although the act of change did not appear until later.

Following the change in alternatives, the interaction measured by both scales went to its maximum. One could argue that the problem solver was now looking for confirmation of his new alternative.

This suggests a cyclical effect in problem solving which departs from the question of the superiority of groups or individuals. The data suggest a time sequence which consists of groups, then individuals, then groups, etc.

Problem solving is not done by the individual alone, nor by the group alone, but is more a mix of both ingredients. The individual in isolation is not the desired goal. Equally clear are the undesirable effects of constant interaction with no place for individual effort. The alternative probabilities changed drastically during the period of zero interaction. One may argue that this was triggered by previous interaction, but the individual effort is apparently an important ingredient.

One may reason the cycle as follows: Early interaction is to explore and probe. The goal at this stage is clearly different from the interaction after the switch in alternatives. It should not be expected that alternatives will actually change in probability ratings at that time.

The heavy interaction in Figure 5-2 for the week ending 4 May is for confirmation; and, as illustrated in the figure, the favored plan becomes still more favored. The process may be illustrated in a model as shown in Figure 5-3. Refutation following post interaction feeds back to a search for new ideas. A confirmation then has a short feedback loop to post interaction, which accounts for the high level of interaction after the initiation of new ideas. The confirmation

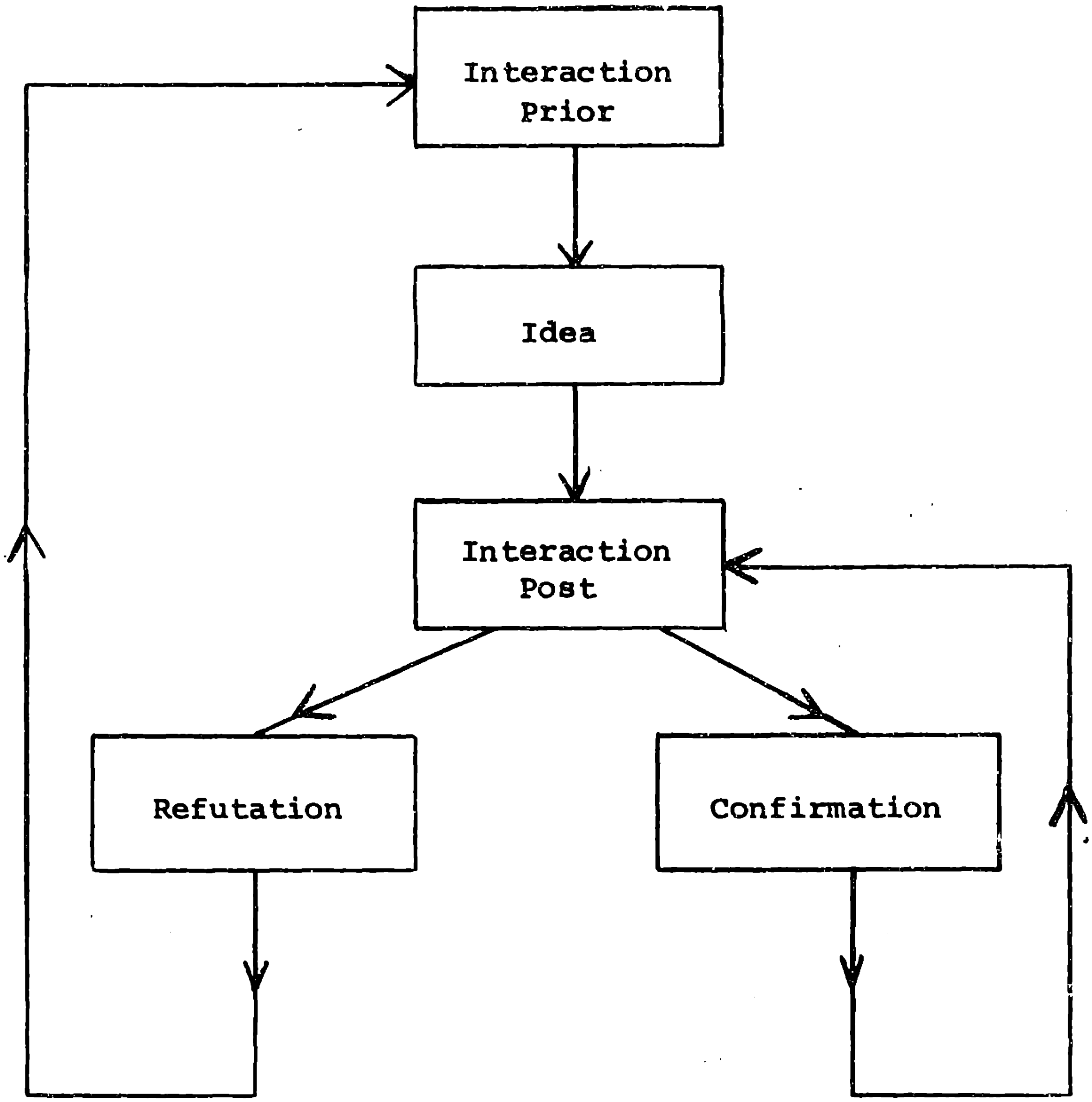


Figure 5-3. The Cycle Model

is recursive since more and more interaction is sought in order to indulge in maximum feedback and gain broad social support.

Recognizing that it is a cycle, it is difficult to tie down the starting point. In many contracts of the sort considered in this study, much work is done during the bidding stage so that the reader must be wary of assuming that the extreme left side of the interaction graphs are the true starting points.

Now this process might possibly be enhanced through the encouragement of very early interactions between the team members and colleagues, both within and outside of the organization. It should not be expected that ideas will change at that time. Following that and during a period of minimum interaction, one may expect new ideas to emerge and existing alternatives to change in priority.

It should be cautioned that the forced interactions in replacing the natural interactions may not have the same effects. This clearly lends itself to experimentation where the meetings might be planned in such a way as to optimize the problem-solving procedure.

A further study would be a micro-analysis that would take only a few subproblems but would increase the sampling frequency to daily instead of weekly. A model showing daily steps in a problem-solving example is shown in a later section.

Further experiments should include the influence of spatial relationships. Recognizing the cycle between interaction, individual work, and further interaction, the space must be so arranged as to encourage this. Many comments from the organizations reflected the influence of space on the time lag between idea generation and interaction. Close working conditions encouraged the problem solver to try out his new ideas that day on several of his colleagues.

Chapter VI

PHYSICAL LAYOUT EFFECTS ON INTERACTION

Up until now, we have been concerned with the effects of internal consulting on R & D performance. Now we will turn to the very important question of factors which themselves encourage or discourage internal consulting. Critical among these is the physical configuration of the office space within which the consultant and information-seeker must work.

To determine the impact of physical separation and floor plan configurations, each individual in each of the organizations was first asked, in several ways, to indicate the people with whom he communicated most frequently. Individuals could then be connected by communication bonds in a manner quite similar to the sociometric techniques which have become standard in social psychological practice.

Sociograms

The sociometric method of studying group structures was developed by Moreno (1934). His original objective was to establish the pattern of feelings of acceptance and rejection that exists among the members of a group. The method involves asking each member of a group to name the other persons in the group with whom he would like to engage in some particular activity.

The sociometric method has been extended to include other ways of discerning the relations among people, beyond what is revealed in their reported feelings about others. Loomis (1941) ascertained the frequency of visiting, eating meals together, and lending farm equipment among the families of a village in New Mexico. Such data made it possible to construct a sociogram which pictures for the whole group all the patterns of mutual like, dislike, and indifference, and the patterns of interaction.

Reliability

As previously employed, the sociometric test has been found to have an average reliability of .95 . This is based on tests given on four successive weeks in which campers were allowed to choose their tentmates (Newstetter, 1938). Zeleny (1938) reports that at the college level, using also five choices and one criterion (membership in a discussion group), reliability coefficients range from .93 to .95 from tests given on successive days. These coefficients are based on the extent to which the subject is chosen by others on two or more occasions; they relate to the choices individuals receive from others. Jennings (1950) has a more stringent comparison since she utilizes unlimited choices and a much longer retest interval. However, even under these conditions there is a high test-retest correlation.

Previous Correlations

The choice of colleagues for interaction and other sources of influence have been the subjects for several investigations. Menzel and Katz (1955) point out, "sources of influence which are not inherently relevant to the subject matter at hand must be considered, even where expert opinions and specialized sources of information are available." They go on to state that among the sources which influence an individual's behavior, with little respect for the boundaries of the subject matter, are the enduring networks of social contact. I propose that it goes still further and that the individual is largely in contact with those in close physical proximity and that the space arrangement will therefore greatly affect the interaction pattern.

Berelson (1954) points out that in politics neither the newspaper editor nor even the ward heeler appears to affect the individual's vote as powerfully as his parents, his spouse, or his ethnic and religious loyalties. Brown (1965) states that proximity in space is a prerequisite to interaction. He states that nearness of a dwelling unit or work position is known to favor interaction and friendship.

Festinger, Schachter, and Back (1950) find that, in a housing project for married veteran students, friendships most often develop between next door neighbors. The most widely popular people in the project are those whose apartments are so located as to bring them into contact with many others. These families have apartments that are either located centrally in a court or else open on stairways.

Newcomb (1961) studied the acquaintance process in a student residence at the University of Michigan. The college assigned rooms arbitrarily and the researcher was able to assess the influence of proximity upon the development of friendship. He found that proximity favored friendship. He stated further that the house was small and therefore the most spatially remote members had ample opportunity to meet.

The anthropologist, Edward T. Hall (1959), has had some stimulating things to say about spatial relations and the quality of social interaction. In his book, The <u>Silent Language</u>, he discusses an airport waiting-room and states that the spacing alone enables one to infer the approximate quality of the social relations linking the people present. He maintains that unacquainted persons, strangers, will stay at a certain distance. He maintains that if there is enough room, they will not sit side by side but will take alternate or more remote seats. He concludes that spatial distance is a large determiner of social interaction.

Mutual Dependence of Activity, Interaction and Sentiment

The book by Newcomb, Turner and Converse (1965) added the subtitle, "The Study of Human Interaction." They clearly state in the forward that their basis for inclusion and exclusion of material for the text has been their conviction that most of the important notions can be organized around the phenomenon of human interaction.

Homans' evidence (1950) is taken from a famous early study of workers in an electric manufacturing firm (Roethlisberger and Dickson, 1939). In this study, the "bank wiremen" assigned by management to work together interacted with one another frequently and also became friendly. Homans states, "The relationship between association and friendliness is one of those commonly observed facts that we use all the time as a guide for action."

Homans states further that if it is true we often come to like the persons with whom we interact, then it is also true that we tend to interact with persons that we already like. That is to say that interaction and sentiment are mutually dependent.

Additional evidence comes from Whyte's study (1956) of parties held in a suburban residential development known as Park Forest. Whyte read the social notes in the Park Forest Reporter for a three and one-half-year period. He summarizes the evidence as follows: "The guests at any one party come from a fairly circumscribed geographic area . . . the groups usually formed along and across streets; rarely did the groupings include people on the other side of the back yard . . . Three years later, new people have moved in, others have moved out, yet the basic patterns are unchanged."

Allen and Cohen (1966) used a sociometric questionnaire to determine the structure of information networks in an R & D laboratory. Festinger (1950) used a sociometric questionnaire and found a strong relationship between location of living quarters and degree of interaction. In a further study by Allen (1967), a high negative correlation was found between separation distance and technical discussion choices.

Several studies have examined the relationship between distance and marriage selection. Abrams (1943) and Kennedy (1943) show that there is an inverse relationship between the distance separating potential marriage partners and the number of marriages. Thus, in New Haven, 76 percent of the marriages in 1940 were between persons living within twenty blocks of each other and 35 percent between persons living within five blocks of each other. This evidence plus other "determinants of friendship" is treated in Gouldner and Gouldner (1963).

Physical Layout – Organization A

Figure 6-1 shows the physical layout of the sections under consideration in Organization A. The physical layout was obtained by pacing off and drawing the relationships between the various sections.

On the sixth floor (Figure 6-1) there is an Electrophoresis section separated by approximately forty yards from the next section which is the Hematology section. The distances are approximations since floor plans were not available; but for these purposes they will suffice, and if the writer's paces represent a yard, they are then quite close to true distances.

The Hematology section is ten yards from the elevator and an additional ten yards to the Blood Bank section.

On the fifth floor, directly beneath the Hematology group and ten yards to the left of the elevator, is the Microbiology section. There are no other sections on the fifth floor.

On the fourth floor the Chemistry section is ten yards to the right of the stairway and is located directly beneath

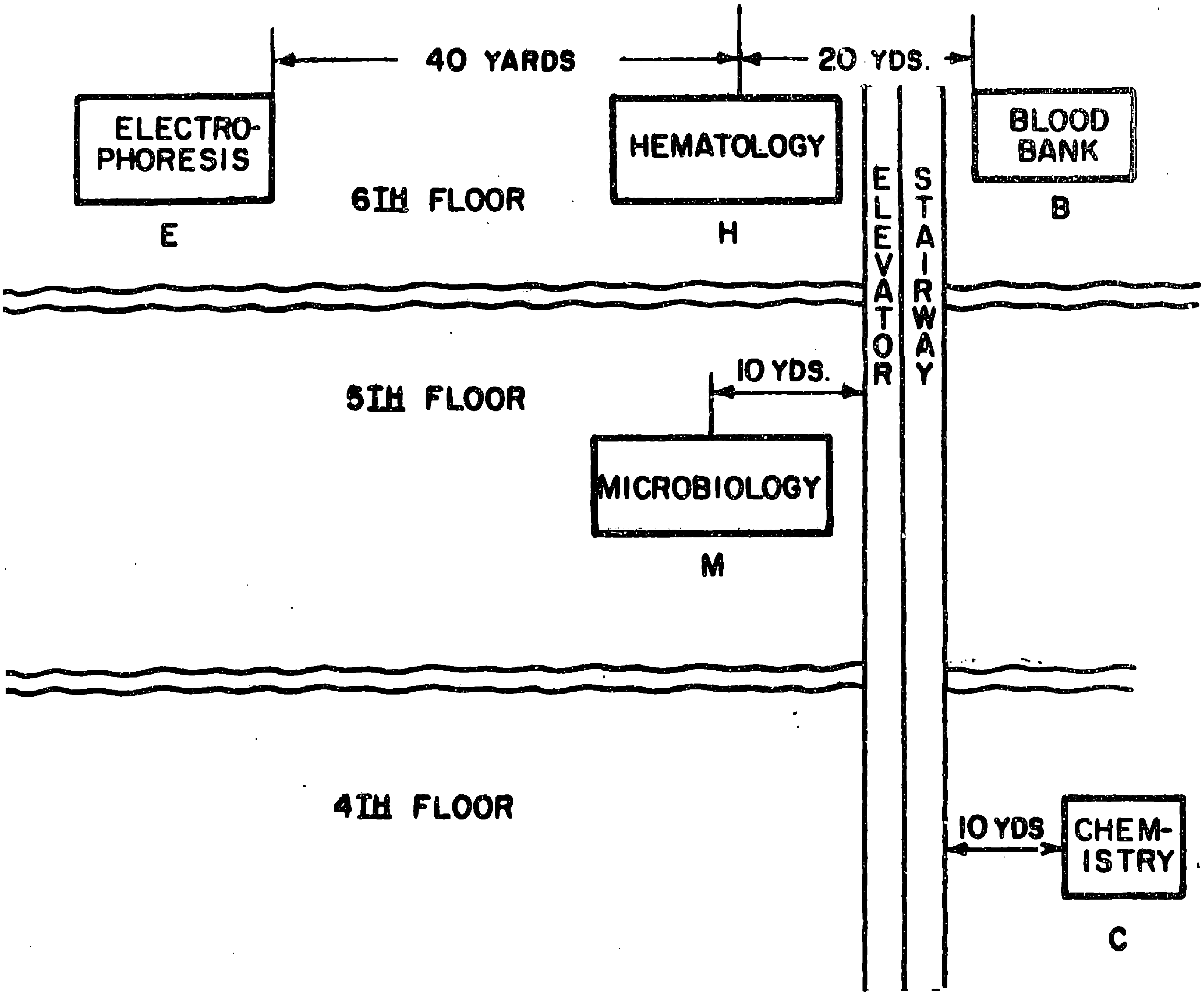


FIGURE 6-1 PHYSICAL LAYOUT OF SECTIONS--PARALLEL ORGANIZATION A

the Blood Bank group but two floors below. There are no other sections on this floor.

The building is modern, approximately two years old, the lighting is good, the halls are wide and, in general, the housekeeping appears excellent.

Parallel Organization B – Physical Layout

Figure 6-2 shows the physical layout of the six sections in Organization B. The physical layout was again obtained by pacing off the distances as was done for Organization A.

On the first floor there are two sections that are located adjacent to each other: the Radio-Isotope section and the Thyroid section. The approximate distance between the doors to each section is thirty yards.

The Aldostrone section is directly above the Radio-Isotope section on the second floor, west wing. This is approximately fifty yards from the elevator and stairway. In the south wing of the second floor there are three sections called Steroid I, Steroid II, and Steroid III. Steroid sections I and II adjoin each other, with Steroid III directly across the hall.

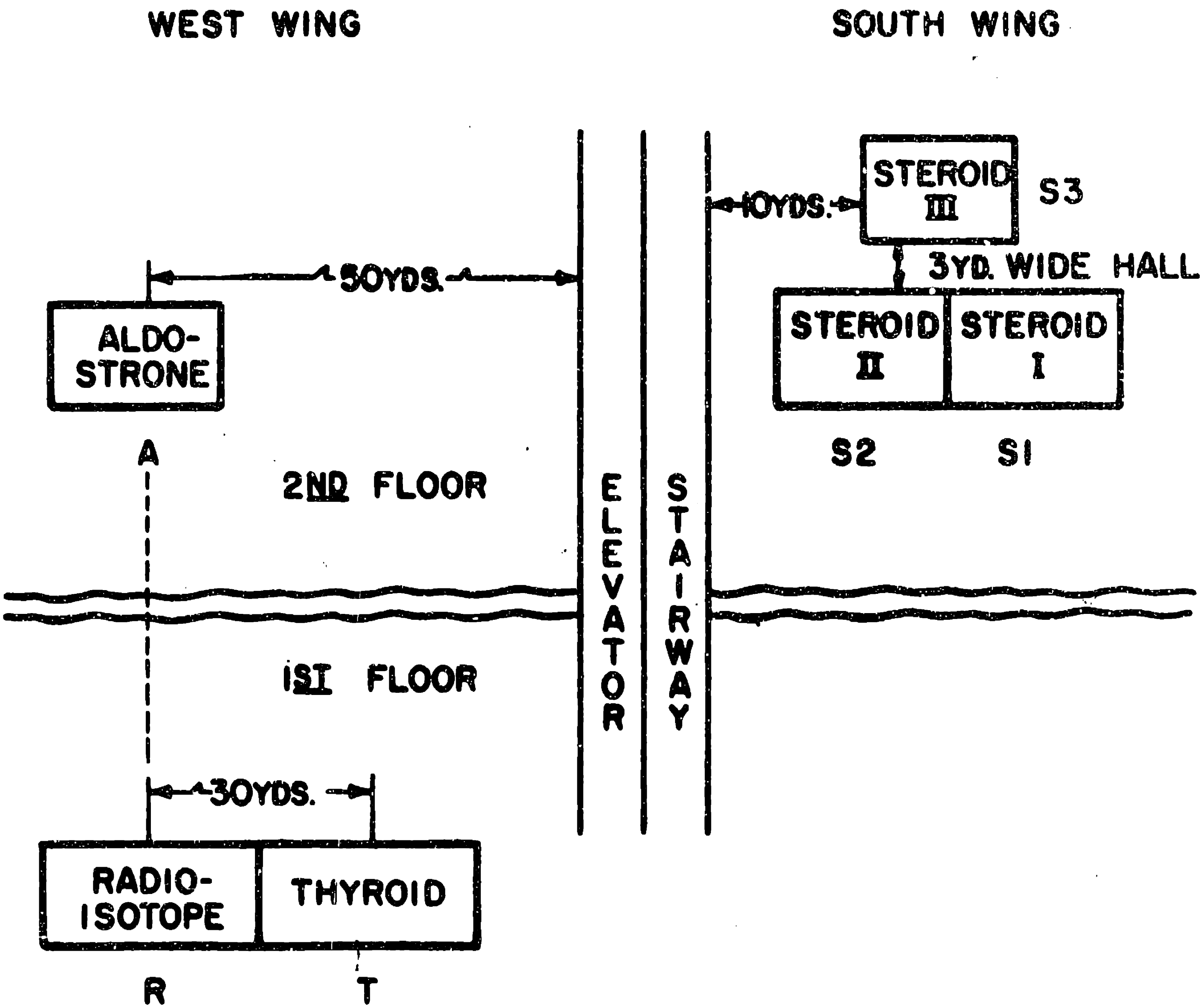


FIGURE 6-2 PHYSICAL LAYOUT OF SECTIONS--PARALLEL ORGANIZATION B

Technical Discussion

For ease of analysis, let us use the following abbreviations:

Organization A	Organization B
E = Electrophoresis	S3 = Steroid III
H = Hematology	S2 = Steroid II
B = Blood Bank	S1 = Steroid I
M = Microbiology	A = Aldostrone
C = Chemistry	R = Radio-Isotope
O = Other	T = Thyroid

Tables 6-1 and 6-2 indicate the amount of technical discussion that takes place between individuals in the various sections. Each number in the cell represents the selection of an individual in response to the following question:

> Please name those people in the company with whom you often discuss technical matters (at least once/month).

The Technological Communication Survey was administered and collected the same day. This has the advantage of eliminating bias due to response ratios and enables the sample to obtain a 100% response.

The number of respondents for each of the sections considered are shown in Tables 6-3 and 6-4. In those few cases where persons selected colleagues outside of their sections for technical discussion, the people who did the selecting were

Section	Technical Discussion Choices					
	E*	H*	B*	M*	C*	O*
Electrophoresis (E)	10	0	0	4	0	0
Hematology (H)	0	34	4	2	0	2
Blood Bank (B)	0	0	47	0	0	1
Microbiology (M)	0	0	0	28	0	3
Chemistry (C)	0	0	1	1	13	2

*All letters in column headings refer to same sections as indicated in row headings with the addition of "O" for other.

Table 6-1. Technical Discussion Affected by Physical Layout Parallel Organization A

Section	Technical Discussion Choices					
	S3*	S2*	S1*	A*	R*	T*
Steroid III (S3)	6	1	3	1	1	1
Steroid II (S2)	0	6	3	2	0	0
Steroid I (S1)	0	2	10	1	0	0
Aldostrone (A)	0	0	0	14	0	1
Radio-Isotope (R)	0	0	0	0	43	2
Thyroid (T)	0	0	0	2	0	61

*All letters in column headings refer to same sections as indicated in row headings.

Table 6-2. Technical Discussion Affected by Physical Layout Parallel Organization B

1	2	3	4	5
Section	N Respondents in Section	N_T Total Number of Choices for Technical Discussion	N_S Total Number of Choices for Technical Discussion in Own Section	$\frac{N_S}{N_T}$ %
Electrophoresis (E)	4	14	10	71
Hematology (H)	10	42	34	81
Blood Bank (B)	9	48	47	98
Microbiology (M)	8	31	28	90
Chemistry (C)	9	17	13	76
Total	40	152	132	86.9

Table 6-3. Percentage Chosen in Own Sections for Technical Discussion Parallel Organization A

1	2	3	4	5
Section	N Respondents in Section	N_T Total Number of Choices for Technical Discussion	N_S Total Number of Choices for Technical Discussion in Own Section	$\frac{N_S}{N_T}$ %
Steroid III (S3)	7	13	6	46.1
Steroid II (S2)	11	11	6	54.5
Steroid I (S1)	11	13	10	77.0
Aldostrone (A)	8	15	14	93.4
Radio-Isotope (R)	13	45	43	95.5
Thyroid (T)	24	63	61	97.0
Total	74	160	140	87.5

Table 6-4. Percentage Chosen in Own Sections for Technical Discussion Parallel Organization B

usually new to the group. They usually picked choices from their previous locations. These people were still interacting with their former colleagues. It appears that socialization or perhaps convenience then enters and the technical discussions become pretty much limited to one's own work group.

These findings were reported to the directors who confirmed the fact that they suspected high interaction within each group and very little interaction between the groups. However, the extent of the problem becomes strikingly vivid as one observes the data.

To further understand the lack of intergroup communication, it is necessary to look into the training necessary for the sections and the equipment involved. Some pieces of equipment are peculiar to a particular section but in general the equipment is standard. The personnel come from similar past training and most have a Bachelor of Science degree in biology.

The bottom lines in Tables 6-3 and 6-4 are totals, and the total percentages are obtained by dividing the sum of column 4 by the sum of column 3. The figure of 87.5 in Table 6-4 indicates that 87.5% of the choices for technical discussion for Organization B occur within one's own section. Table 6-3 shows that 86.9% of the choices for technical discussion for Organization A occur within one's own section.

Controlling for Organization

One may reason that the lack of interaction between sections is not so much a physical phenomenon as it is a result of the organizational structure. This is certainly a valid comment and to some extent true. Yet, how might one control for the organizational factor?

Control for organization may be accomplished in several ways. First, one might accumulate data on those individuals who are in close physical proximity but separated organizationally. In this sample, such data could not be obtained, since the physical clusters were very much along organizational lines.

One could turn to a second method and perform the following experiment. Take several individuals from one section and remove them from the cluster and place them in another section. One would wait a period of time for adjustment to take place and then measure the choices for technical discussion. This is one approach that I would recommend for future research. The facilities are available and the change in technical discussion choices over time due to a change in location should be most informative.

In the present research, a third method was used that considers controlling for organization by studying individual sections separately. For purposes of illustration, a section from Organization A and a section Organization B are considered.

Figure 6-3 is a typical example of the technical discussion choices within a particular section. Each number represents a person, and the location of the number corresponds to the individual's location in the section. The thirteen selections represented by arrow heads in Figure 6-3 correspond to the thirteen that appear in the chemistry cell of Table 6-3.

The section head is number 1 and is located in the center of the section. Most members of the group, with the exception of numbers 7 and 8 who appear to work quite independently, chose number 1 as one of the persons that they would move to for technical discussion. One may consider the choices for technical discussion not considering the supervisor. Such a diagram may be seen in Figure 6-4.

Figures 6-3 and 6-4 indicate that the technical discussion choices are almost exclusively neighbors. Two chooses three, three chooses two, four chooses five, six chooses five, eight chooses seven. The only violation is when nine chooses six. This one case may be explained by the fact that nine is a girl and six is a boy and perhaps chemistry is at work in addition to the prescribed activities

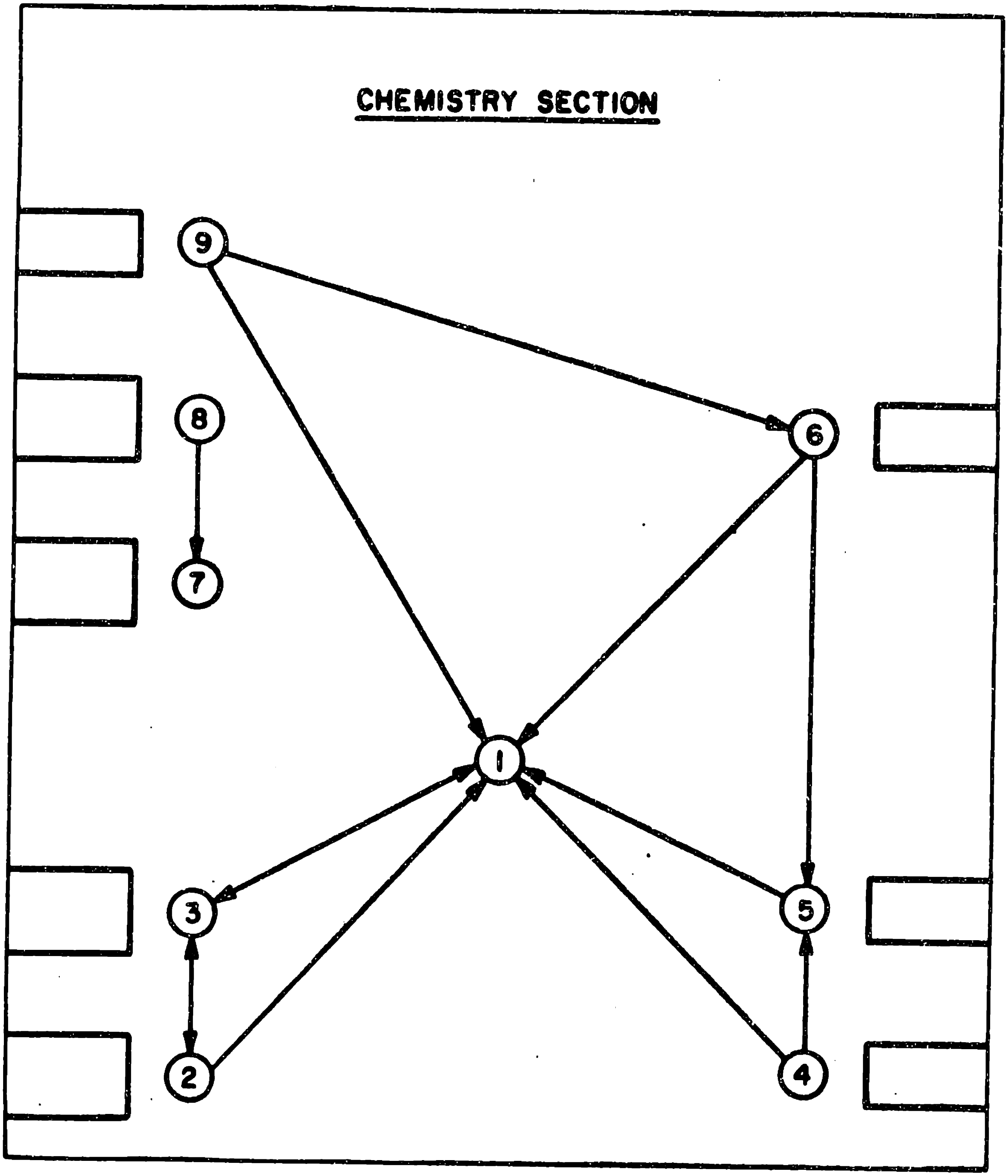


FIGURE 6-3 INTRA SECTION TECHNICAL DISCUSSION CHOICES ORGANIZATION A

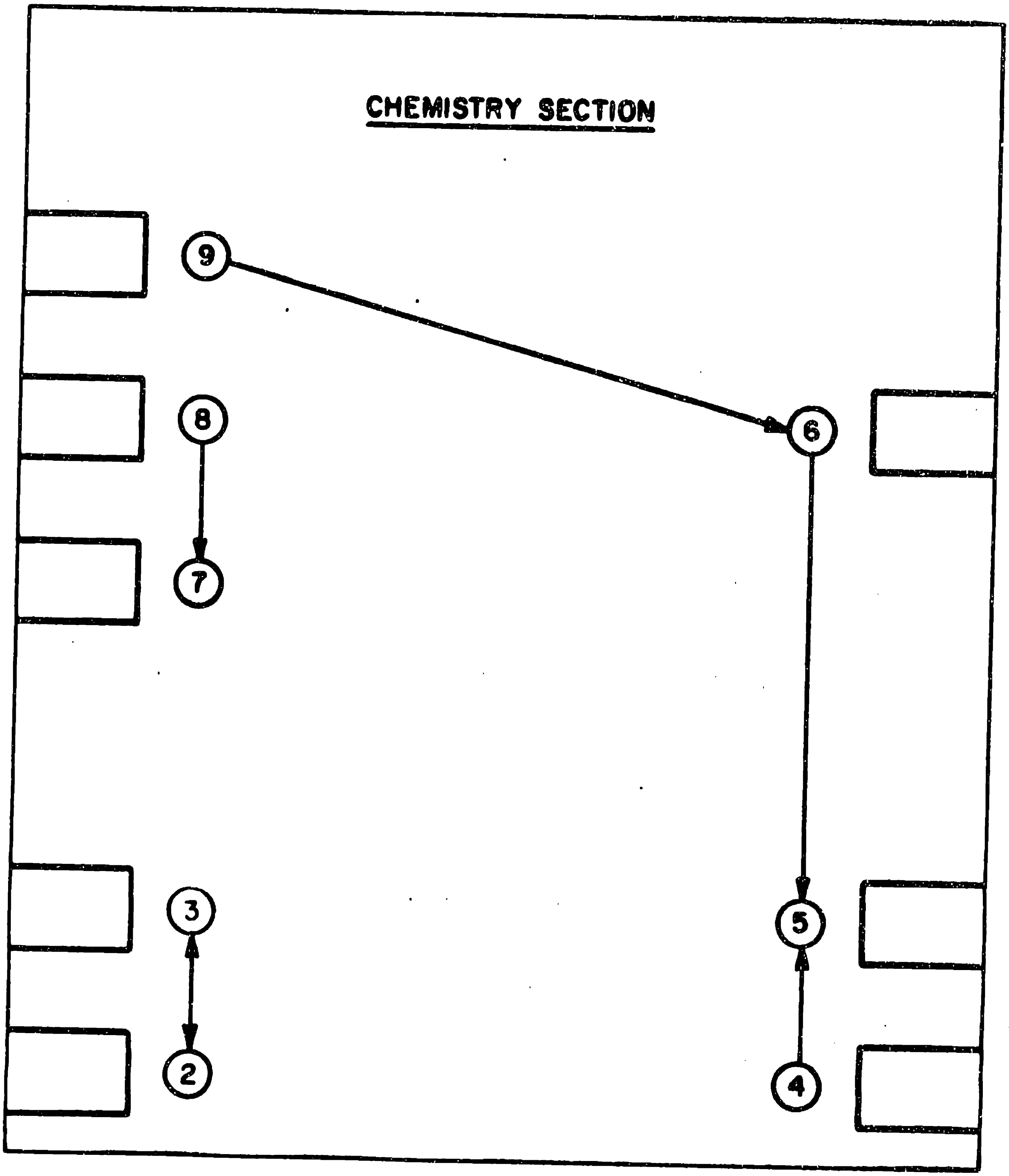


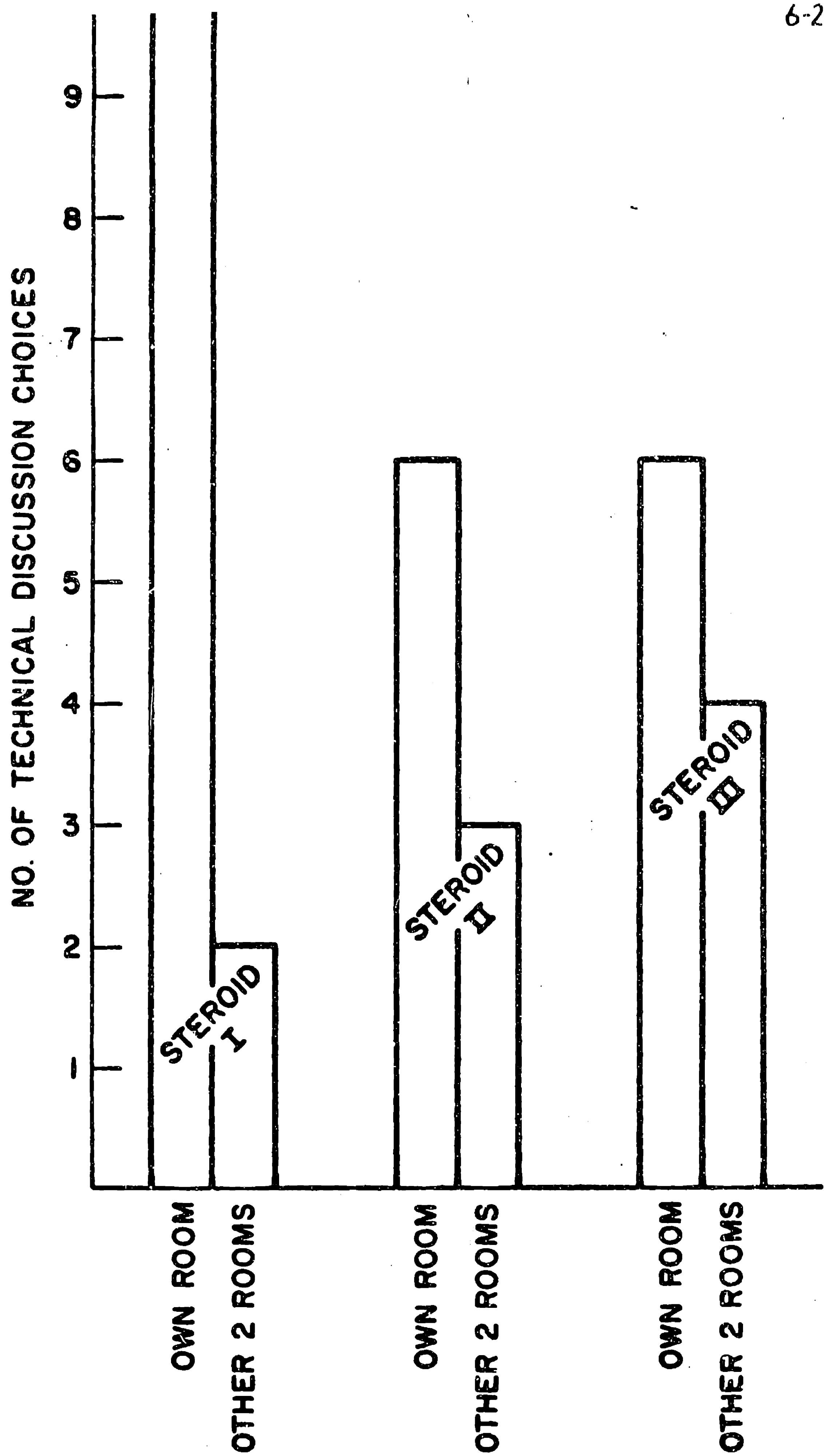
FIGURE 6-4 INTRA SECTION TECHNICAL DISCUSSION CHOICES CONTROLLING FOR LEADER

of the chemistry section.

A second illustrative example will now be considered. The section is from Organization B which presented an extremely interesting opportunity for study. Figure 6-2 indicates that on the second floor, south wing, there is a section called Steroids that is divided into three separate rooms. The Steroid I and Steroid II rooms are adjacent to each other with Steroid III directly across the hall. One is in a position to observe the number of technical discussion choices within the same section and both in and out of the same room.

A Fisher Exact Test shows significantly that people in S3 choose more colleagues for technical discussion in S3 rather than in S2 or S1. This same phenomenon may be observed regarding S2 and S3. Colleagues strongly prefer to choose colleagues for technical discussion within the same room rather than leaving the room and going to an adjacent room or across the hall. Figure 6-5 graphically displays the number of technical discussion choices in one's own room as opposed to the other two rooms of the same section.

The physical layout in relation to the technical discussion choices has been analyzed using several measurements. The Technological Communication Survey was employed for a set of parallel organizations , and the response by section showed


NO. OF TECHNICAL DISCUSSION CHOICES
9
8
7
6
5
4
3
2
1
STEROID I
STEROID II
STEROID III
OWN ROOM
OTHER 2 ROOMS
OWN ROOM
OTHER 2 ROOMS
OWN ROOM
OTHER 2 ROOMS

FIGURE

high internal communication and little interaction over physical distance. The next measure considered the intra-sectional technical discussion choices in a closely grouped section. In this analysis, colleagues chose neighbors and seldom were their choices on the other side of the section. The section that was divided into three rooms showed at a statistically significant level that colleagues interact almost totally with colleagues within the same room.

Physical Separation

As a final measure of the relationship between those individuals selected for technical discussion and the physical arrangement, consider an integrated section spread out over some distance, namely, the Rheumatoid Arthritis section. The physical arrangement is shown in Figure 6-6. It is all on one floor, with a straight hallway separating the offices as shown.

The number of technical discussion choices was arrived at by considering Question 2 in the Technological Communication Survey. Next to each choice, the distance was calculated from the respondent's office to the chosen man's location. The figures are shown under the column "Chosen" in Table 6-5. The individuals not named are listed under "Not Chosen." The analysis of variance test results in a

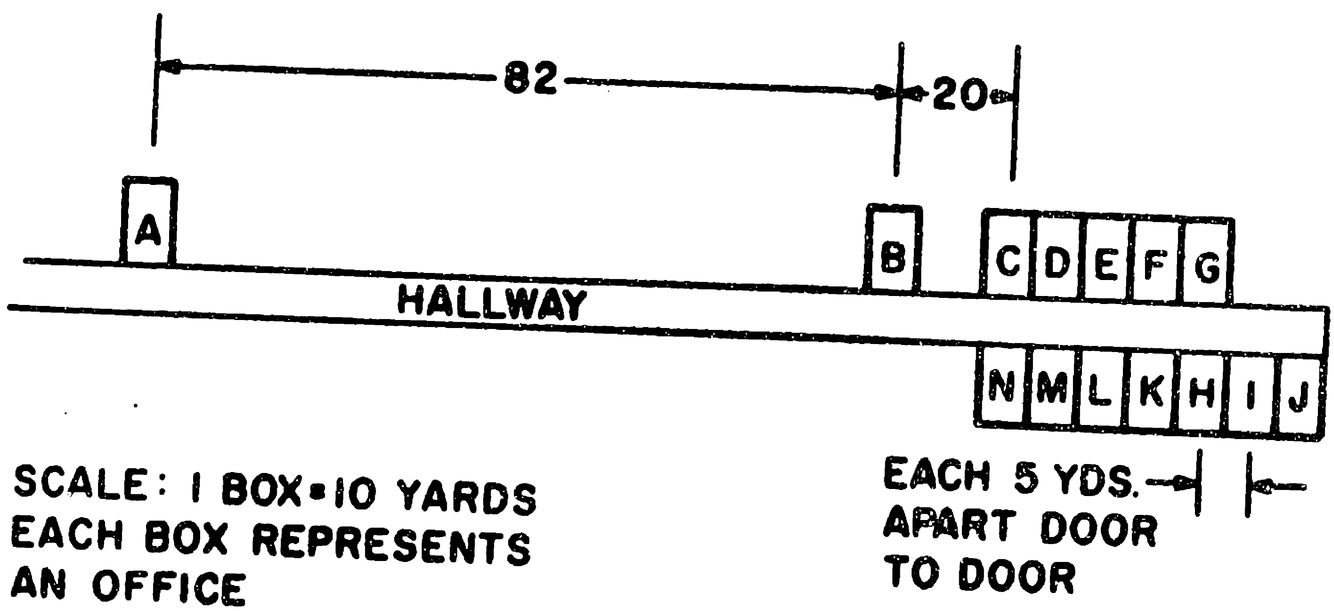


FIGURE 6-6 PHYSICAL ARRANGEMENTS - RHEUMATOID ARTHRITIS SECTION

Table 6-5

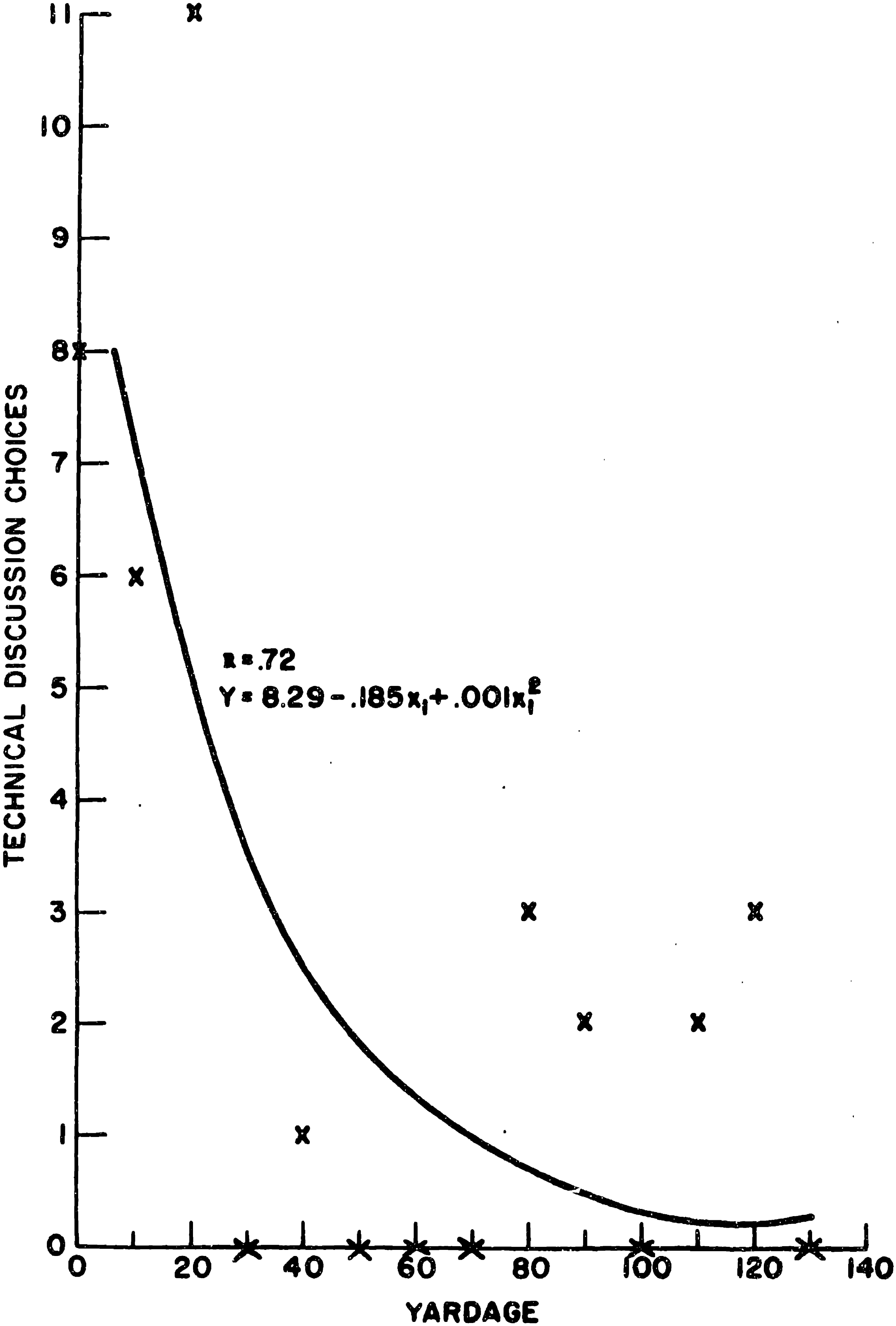
Yardage Separating Those Chosen and Those Not Chosen for Technical Discussion — Parallel Organization A

	Number of Selections	
Yardage	Not Chosen	Chosen
0	16	8
10	22	6
20	37	11
30	11	0
40	4	1
50	0	0
60	1	0
70	0	0
80	2	3
90	1	2
100	10	0
110	38	2
120	35	3
130	24	0

$F = 8.615$
$p = .0036$

$F = 8.615$ and $p = .0036$. The less the physical distance between colleagues, the greater the liklihood of technical discussion.

A plot of the frequency of technical discussion choices versus distance is shown in Figure 6-7. This is calculated within one section so that differences in technical skills or



11
10
9
8
7
6
5
4
3
2
1
0
TECHNICAL DISCUSSION CHOICES
R = .72
Y = 8.29 - .185x1 + .001x1^2
0
20
40
60
80
100
120
140
YARDAGE

organizational assignments may not account for the lower or higher frequency of choices. The number of choices sharply drops off as the distance is increased. The correlation coefficient is .72 and the least means square equation is $y = 8.29 - .18X_1 + .001X_1^2$.

Summary

It has been illustrated by many different measures that colleagues interact with other colleagues who are in close proximity. Consider this data in light of the findings of Chapter IV. The evaluations correlate high performance with technical discussion choices beyond one's immediate group. Most arrangements locate the assigned group in close proximity. Following our reasoning, this would then lead to high interaction. Unfortunately, this high interaction is not related to success but it is the interaction with the technical staff that results in high performance. *Unfortunately, one can only conclude that our present layouts only discourage the very interactions that would result in improved performance*.

Chapter VII

INTERACTION AFFECTING SOURCES OF IDEAS

During the course of the post-project interviews several participants were asked if they could plot out a recent problem solution. It was explained that the days and the ideas and the sources of these ideas must be related.

Figure 7-1 displays the problem-solving progression employed by one scientist. The scientist attended a lecture on a topic somewhat removed from his research area but still close enough to serve as an idea generator. (Menzel and Katz, 1955, point out the importance of considering sources of influence which are not inherently relevant to the subject matter at hand.) The scientist then returned to the laboratory and considered four alternative solutions, α, β, γ, and δ.

The scientist communicated with several technicians and physicians who found difficulties with each of the proposed solutions. The scientist then altered alternative α, which may now be called α', and eliminated β, γ, and δ. He then added alternatives ϵ and ζ.

In searching for the best of the present alternatives, he tried several books but was unsuccessful in resolving the present dilemma. As a result of failing with that information

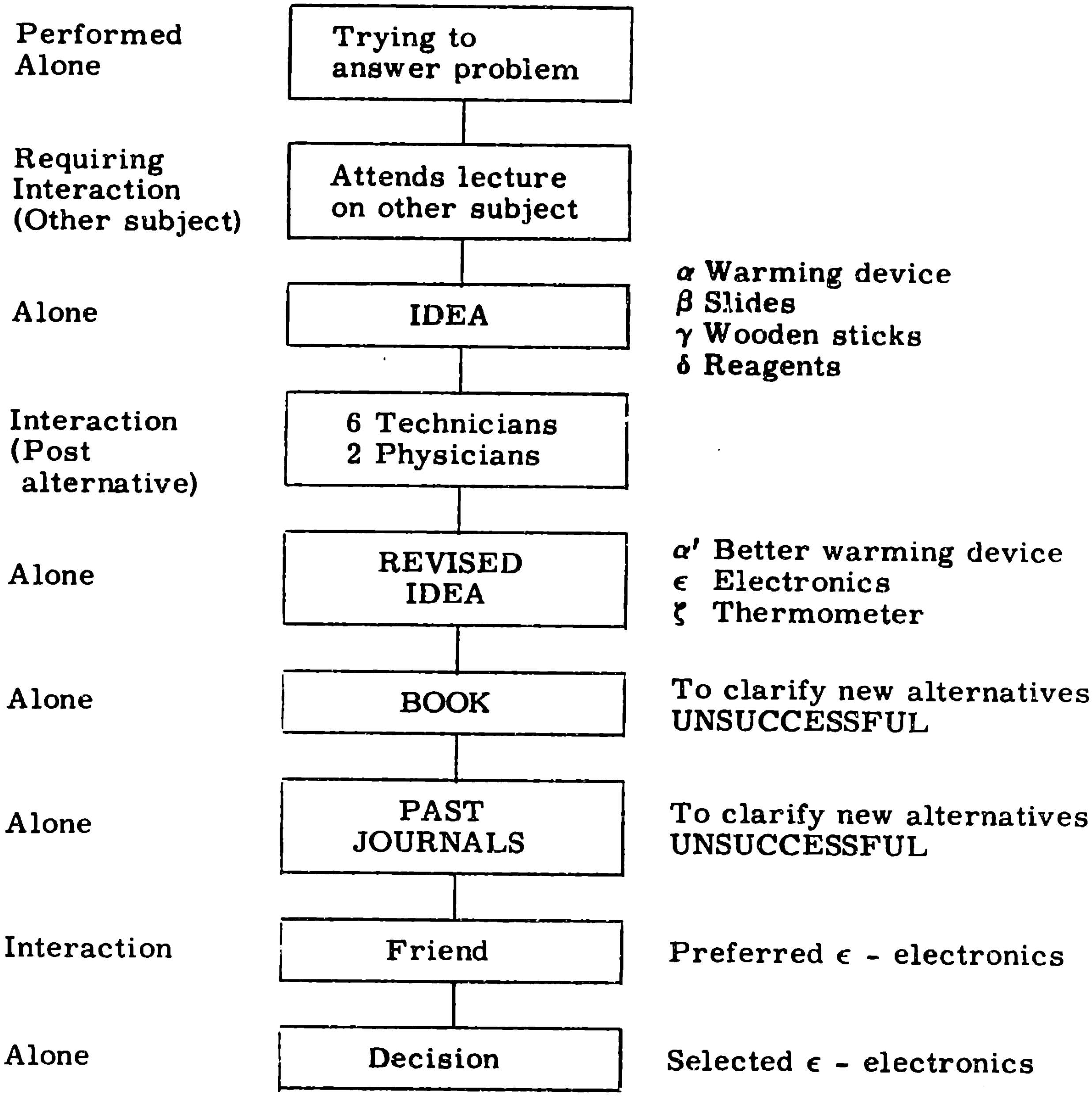


Figure 7-1. The Complex Progression

source, he then went to another, namely, past journals. That too was unsuccessful.

The scientist approached a friend and during that interaction good arguments were presented for alternative ϵ. The final decision was the adoption of alternative ϵ.

This entire process took place over a period of only four days, so that this researcher was able to be on the scene and plot the daily changes with the participant.

This description raises many questions, perhaps more than it answers. Nevertheless, the cycles of interaction and separate work are consistent with the earlier findings on the interactions related to the changes in probabilities of alternatives.

It is difficult to identify the single step in the complex process that contributed the most to the selected alternative. The lecture on another subject served as an idea generator that was useful. This was in spite of the fact that none of the alternatives considered immediately following the lecture were selected.

The post alternative interaction was just prior to the first time that the ultimately chosen alternative ϵ appeared. Perhaps it was the negative information regarding α, β, γ, and δ that, in Simon's terms, decreased the satisfaction and increased the search which resulted in ϵ.

The sources of information, including books and journals, shed little light on the dilemma which led to the search for a new source as indicated in the next to the last box. The problem solver did not return to his former interaction group.

Idea Generators

In one of the organizations studied, 53 scientists were asked the following question:

> "Please try to think of the most recent research project in which you were engaged, and try to identify the sources of information which were especially helpful to you. (Check all categories that apply.)"

Table 7-1 lists each of the categories as column headings and each of the rows represents an individual. Those respondents who were Ph. D.'s were noted.

There is a significant difference between the Ph. D.'s and the non-Ph. D.'s sources of information. Only one out of eight of the Ph. D.'s named the immediate supervisor as a source of information which was especially helpful. This is understandable due to the autonomy of their position. However, thirty-two of the forty-five non-Ph. D.'s credited the immediate supervisor as a valuable information source.

Relating to internal interaction, one notes the interesting category, "Persons Within Company." Eight of the eight Ph. D.'s credited this source as an especially helpful

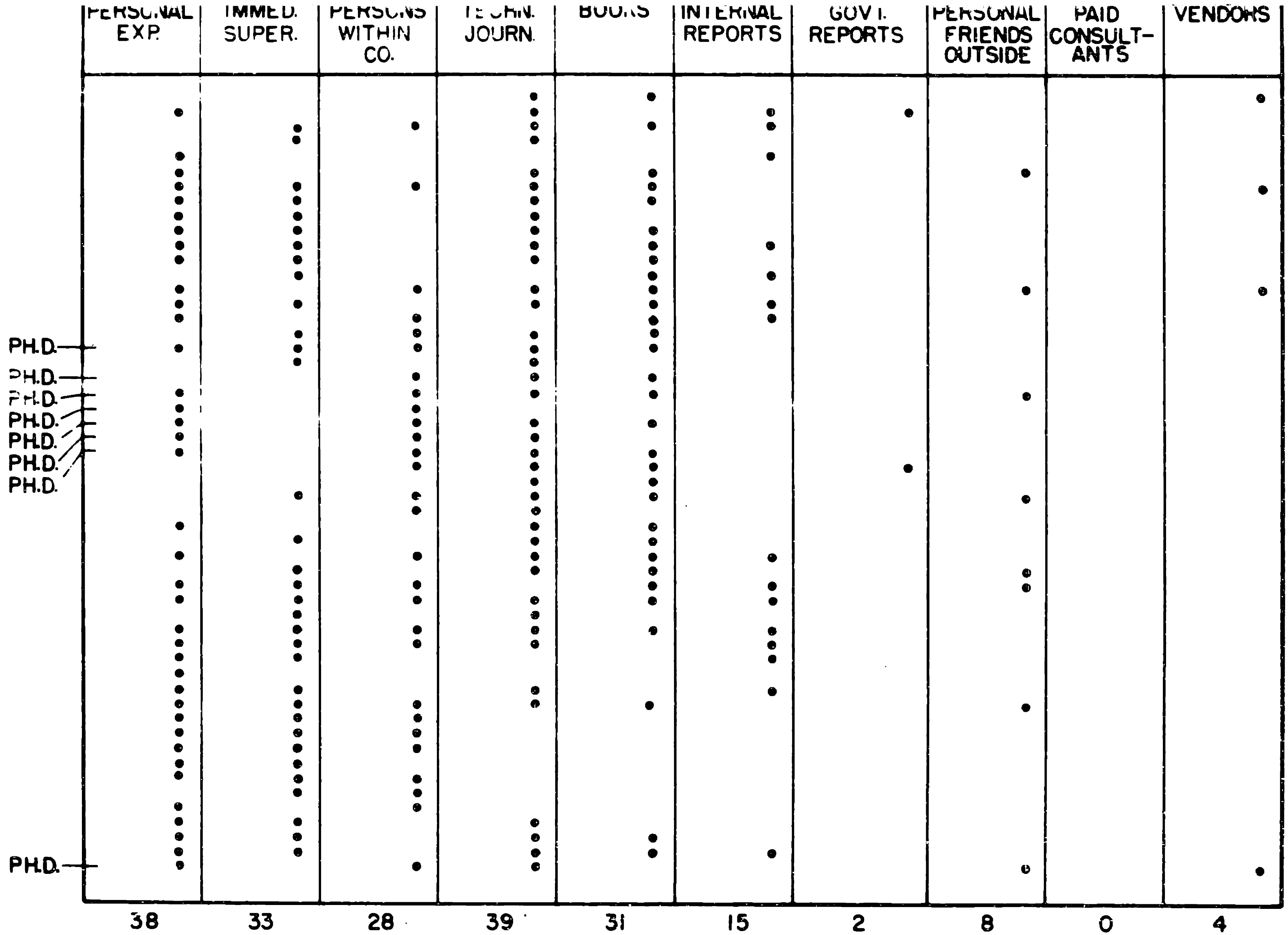


TABLE 7-1 IDEA GENERATOR

idea generator. On the other hand, less than half of the forty-five non-Ph. D.'s named this information source (20 out of 45).

Chapter VIII

SUMMARY AND IMPLICATIONS

The time has now come to stand aside and attempt to integrate the various facets of the investigation. Cyert, Simon and Trow (1956) state that it is extremely doubtful whether the considerable body of decision-making theory that has been available in the past does, in fact, provide a realistic account of decision making in large organizations operating in a complex world.

The relationships between changes in probabilities of alternatives and time of interaction give a basis for a revised model of the decision-making procedure. The cycle model implies that the synergy desired by group activity exists when there is a bridge of independent effort spaced between two periods of interaction.

Synergy may be said to exist in early interactions without exhibiting any change in probability of alternatives or adoption of new alternatives. The early interaction may, without tangible change in probability of alternatives, create dissatisfaction and increase the search for new alternatives. On the other hand, the early interaction may plant the yet unrecognized seed that later is represented as an alternative change.

Simon points out that the information as to what consequences are attached to which alternatives is seldom a "given." The search for consequences is another important segment of the decision-making task. This I believe we see graphically illustrated in what I call the post Δp interactions. The post-project interviews as well as the individual model in Chapter VI clearly illustrate the significance that the engineers and scientists place on this phase of the decision-making process.

There is a myriad of implications to this type of model as well as avenues for additional research. The most immediate requirement for further study consists of a micro-analysis of the role of interaction in decision making. The study would consist of a daily analysis of the changes in probability of alternatives plotted against interaction. This would be similar to the analysis in Chapter VI. The next step in further developing this model would be to code the interactions with special emphasis of the differences between prior and post Δp interactions.

One should recognize the cyclical nature of the decision-making process and the mix required between interaction and individual effort. Planned interactions and individual effort could be studied in the form of a field experiment.

If I may be permitted a moment of self-examination during the course of this research, I clearly interacted, then utilized individual effort, then further interaction, etc. Is this not the very essence of why the university requires students in residence? The non-resident is deprived of the interaction phase of the problem-solving process.

The increased interaction has been shown to lead to increased performance at the graduate level (Hall, 1966). I contend that it is not just the increased interaction but the mix that is important. I am concerned that in many cases an atmosphere is not created that would encourage this type of behavior. When Argyris (1962) strives for "openness" he is attempting to create a climate that fosters both individual and group effort. When McGregor (1966) wrote of the needs for self-fulfillment, he was describing a medium which permitted an opportunity for a man to optimally utilize his resources.

The concern is now the effect of physical layout in interaction. The data show an overwhelming tendency for colleagues to contact other colleagues within close physical proximity. Considering five separate sections of one organization, at the very minimum, 71% of the selection for technical discussion were from the same section. One section chose 98% of their technical discussion choices in the same section.

It was felt that perhaps what was being witnessed was not so much the effect of the physical layout but the organizational characteristics. That constraint was then alleviated by considering the internal workings within the section. In this analysis, one observes the powerful tendency for the technical discussion choices to be the direct neighbor. This implies that the decision maker is reluctant to go beyond a very limited distance.

The above findings are similar to George Homans' (1950) analysis of Roethlisberger and Dickson's work on the bank wiring room (1939). Interactions were heavy among colleagues in the front of the room and the rear, with little interaction between groups.

In an organization operating in parallel to the first one discussed, the average number of choices for technical discussion within one's own section was 87-1/2%. A further consideration dealt with one section in three rooms. In this analysis, it was overwhelmingly demonstrated that a person tended to choose colleagues for technical discussion within his own room!

Recognizing the phenomenon that technical discussion choices are in close physical proximity, as has been illustrated, then two questions arise:

1. Is there a loss of effectiveness by limiting heavy

interaction to one's own section? To put it positively, would there be a gain in effectiveness if one were to move beyond his immediate section?

This question is dealt with in Chapter IV and will be considered shortly. However, for the present let us assume that there is a value in interaction patterns beyond one's immediate group.

2. Shall we endorse Homans' model of the mutual relationship between activities, interactions, and sentiments? If one believes that he can change this relationship, then an approach is open. However, it is much more likely that one will accept the evidence substantiating Homans' theses.

The data clearly imply that the physical layout should be arranged in a manner that would encourage the cycle approach to problem solving as well as interactions beyond the immediate group. E. L. Trist (1963) illustrates how a technological change dictated by rational engineering considerations disrupted the previous interaction. A plant layout change may be said to be analogous to Trist's technologic change and one may expect to see a revised interaction pattern.

Perhaps a circular arrangement with technical discussion choices at equidistant locations is an approach to the problem.

The ability to engage in both interaction and individual work must be made available in accordance with the cycle model. The third criterion is the access of the technical staff beyond one's immediate group.

Having considered Hypotheses 4 and 5, it now remains to consider the first three hypotheses, their implications, and then an overall integration. The first hypothesis was confirmed. It related successful evaluations to interactions with technical personnel outside of the immediate group. It was statistically significant that the high-rated subproblems were those in which there were more interactions with colleagues beyond those directly assigned.

If we were to return again to the bedrock theorists, would we not see encouragement in this direction although perhaps not looked at in this framework? We must create a climate of openness and a reward structure that invites such interaction. Existing conditions only dissuade one from communications with other members of the technical staff.

All steps should be taken to open up this most valuable resource that exists in one's own organization. Seminars should be utilized to a much greater extent and should be heterogeneous in composition, drawing in members from various sections of the technical staff!

It is important to note that increased interaction in the immediately assigned group led to no improvement in evaluation. By merely interacting more often with colleagues of the assigned group, one may expect no change in performance.

Considering Hypotheses 2 and 3, we recognize some similarities to Pelz's findings but only with reservations. There is a positive relationship between interaction and performance. However, one should be cautioned against believing that a higher percentage of interaction will lead to a higher performance.

The greatest contribution from this portion of the results is as follows: Awareness of the positive value of resources within the technical staff and beyond those immediately assigned to a problem should be paramount. Effective use of these resources will often make the difference between survival and failure.

Actually, plans such as the Scanlon Plan were designed to encourage the use of resources throughout the organization. Rewards are based on the overall rather than the individual effort. Unfortunately, one has the strong feeling that we have not begun to scratch the surface in alleviating the reluctance toward free and open communication.

An integration of this research indicates the positive value of increased interaction with the technical staff.beyond one's immediate group. Let me restate that the very interaction that leads to high performance is the very interaction that we are dissuading by our physical arrangements. Let us break down the walls both literally and figuratively that cause sections to internally interact at averages of 88%.

As a final comment I would like to consider Douglas McGregor's three sources regarding the postulating of theories. First, they come from the folklore of our culture. Second, they come from personal experience and observation. Out of our individual experience we develop generalizations and beliefs.

The third source of theory is scientific knowledge. Such knowledge is obtained under a particular set of rules concerning the gathering of evidence. Such knowledge is more consistent and more trustworthy than folklore or individual beliefs. It has been the goal of this research to contribute to this knowledge.

It has been said that scientific works raise new questions and ask to be surpassed and outdated. Perhaps my feelings can best be summed up by a portion of a speech given at the University of Munich in 1918 by Max Weber:

"We cannot work without hoping that others will advance further than we have. In principle, this progress goes on ad infinitum." (Weber, 1919)

APPENDICES

APPENDIX A

INTERACTION DEVELOPMENT RECORD

M.I.T.
Interaction Development Record

Company ______________________

Name: ______________________________ Date ________________

Subproblem: ________________________

1. On the above referenced subproblem please indicate by circling the appropriate numbers how frequently in the past week you communicated with each of your colleagues on work-related matters. (Whether by conversation, memos, seminars etc.)

Name of Colleague	Number of times per week											Other
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____

2. On the above referenced subproblem please indicate by circling the appropriate numbers about how much time was spent in the past week talking or communicating with your colleagues regarding the problem.

Name of Colleague	Number of hours per week											Other
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____
________	0	1	2	3	4	5	6	7	8	9	10	____

3. On the above referenced subproblem please indicate by circling the appropriate numbers how many people you worked with in the past week excluding professional assistants or clerical personnel.

	Number of people worked with											Other
Immediate Group	0	1	2	3	4	5	6	7	8	9	10	____
Other technical groups within the organization	0	1	2	3	4	5	6	7	8	9	10	____
Other technical groups outside of the organization	0	1	2	3	4	5	6	7	8	9	10	____

4. Estimate of probability that a given alternative will be employed. (Please circle a probability estimate for each alternative)

alternatives under consideration											
____________	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
____________	0	.1	.2	.3	.4	.5.	.6	.7	.8	.9	1.0
____________	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
____________	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
____________	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

(circled probabilities should add to one)

5. If information which had a serious impact upon your visualization of the problem or any of its potential solutions was received at any time during the past week, please circle the source(s) of that information on the line below. Sources are defined on the reverse side.

Information Source: L V C ES TS1 TS2 CR PE E

comments (if any): ____

____

6. _____% of total time was spent on this subproblem, this week.

Thank you!

Information Sources

L = literature:	books, professional, technical and trade journals and other publicly accessible written material.
V = vendors;	representatives of, or documentation generated by suppliers or potential suppliers of design components.
C = customer:	representatives of, or documentation generated by, the government agency for which the project is performed.
ES = external sources:	sources outside the laboratory which do not fall into any of the above three categories. These include paid and unpaid consultants and representatives of government agencies other than the customer agency.
TS1 = technical staff:	engineers and scientists in the laboratory who are not assigned directly to the project being considered but are members of your own functional group.
TS2 = technical staff:	engineers and scientists in the laboratory who are not assigned directly to the project being considered and are <u>not</u> members of your functional group.
CR = company research:	any other project performed previously or simultaneously in the lab regardless of its source of funding.
PE = personal experience:	ideas which were used previously by the engineer for similar problems and are recalled directly from memory.
E = experimentation:	ideas which are the result of test or experiment with no immediate input of information from any other source.

APPENDIX B

SOCIOMETRIC QUESTIONNAIRE

Massachusetts Institute of Technology
Technological Communication Survey

:______________________________

Please try to think of the most recent research project in which you were engaged, and try to identify the sources of information which were especially helpful to you. (check all categories that apply)

_____Personal experience
_____Immediate supervisor
_____Persons within the company excluding your supervisor

Names:____________________ ________________________

____________________ ________________________

_____Technical journals
_____Books
_____Internal reports and technical memoranda
_____Reports from other companies
_____Government reports
_____Personal friends outside the company
_____Paid consultants
_____Vendors

Please name those people in the company with whom you often discuss technical matters (at least once/month). Do not limit your response to your own department.

____________________________ ____________________________

____________________________ ____________________________

____________________________ ____________________________

____________________________ ____________________________

Please name the people from the company whom you consider especially good friends.

____________________________ ____________________________

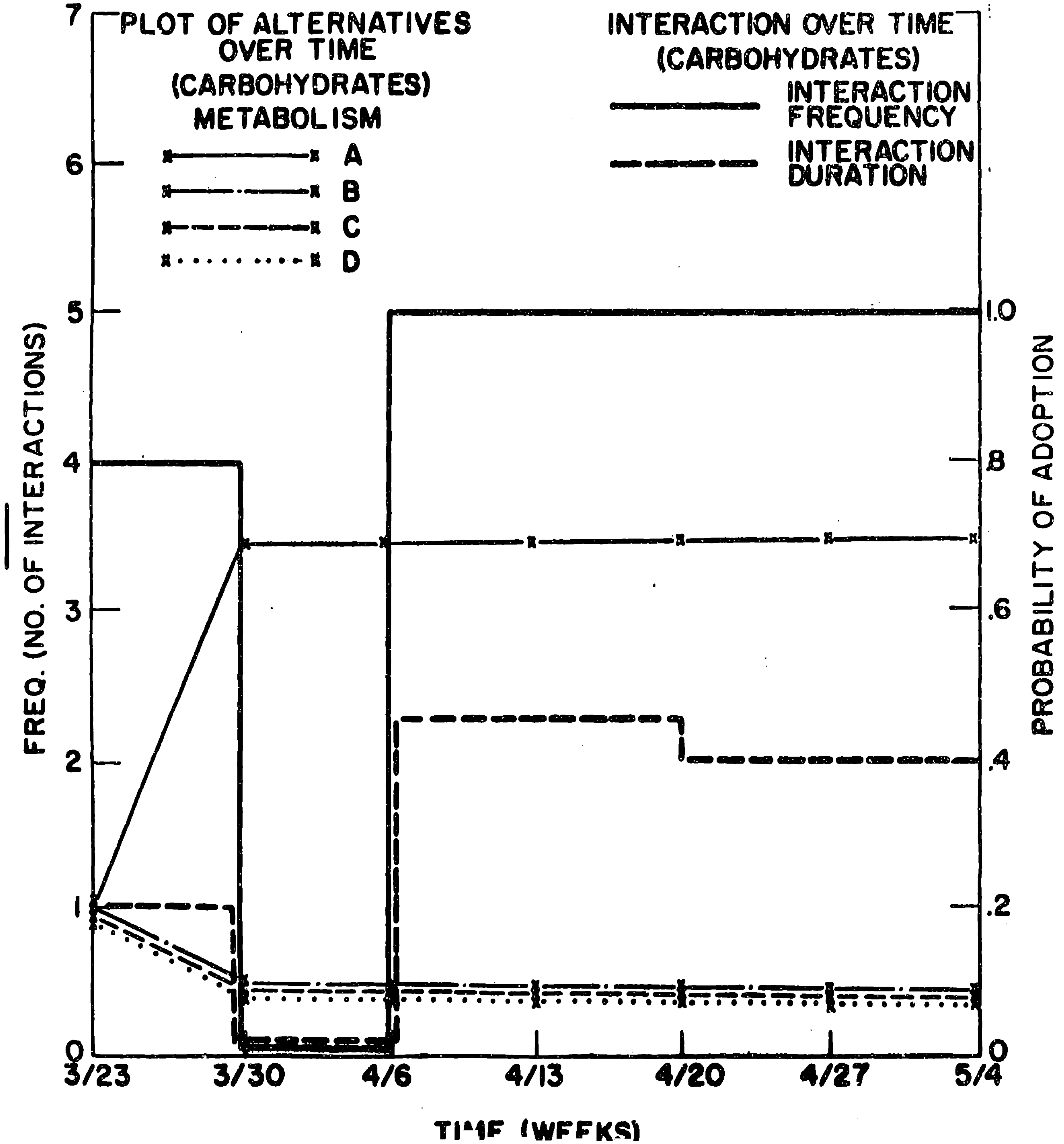
____________________________ ____________________________

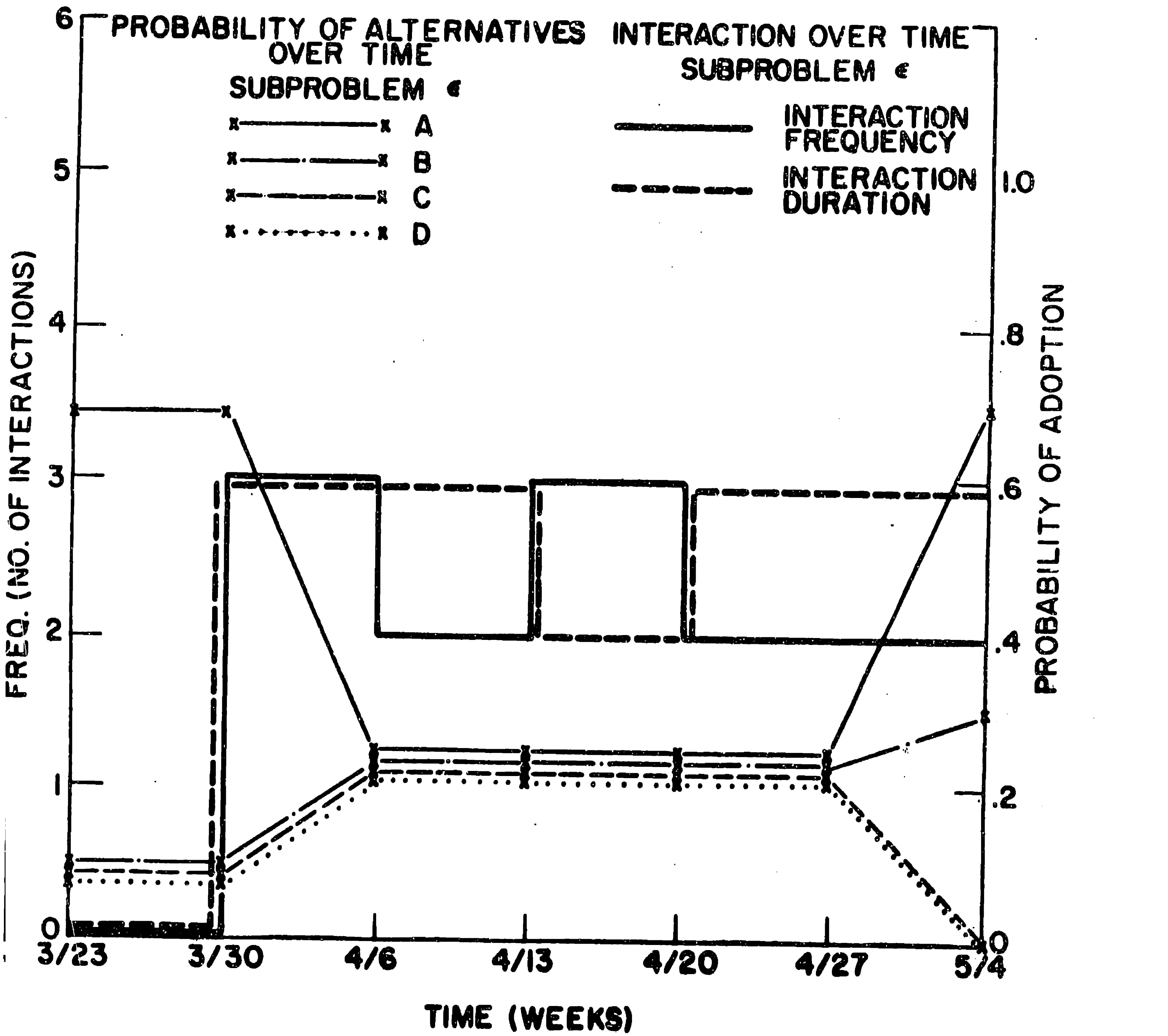
____________________________ ____________________________

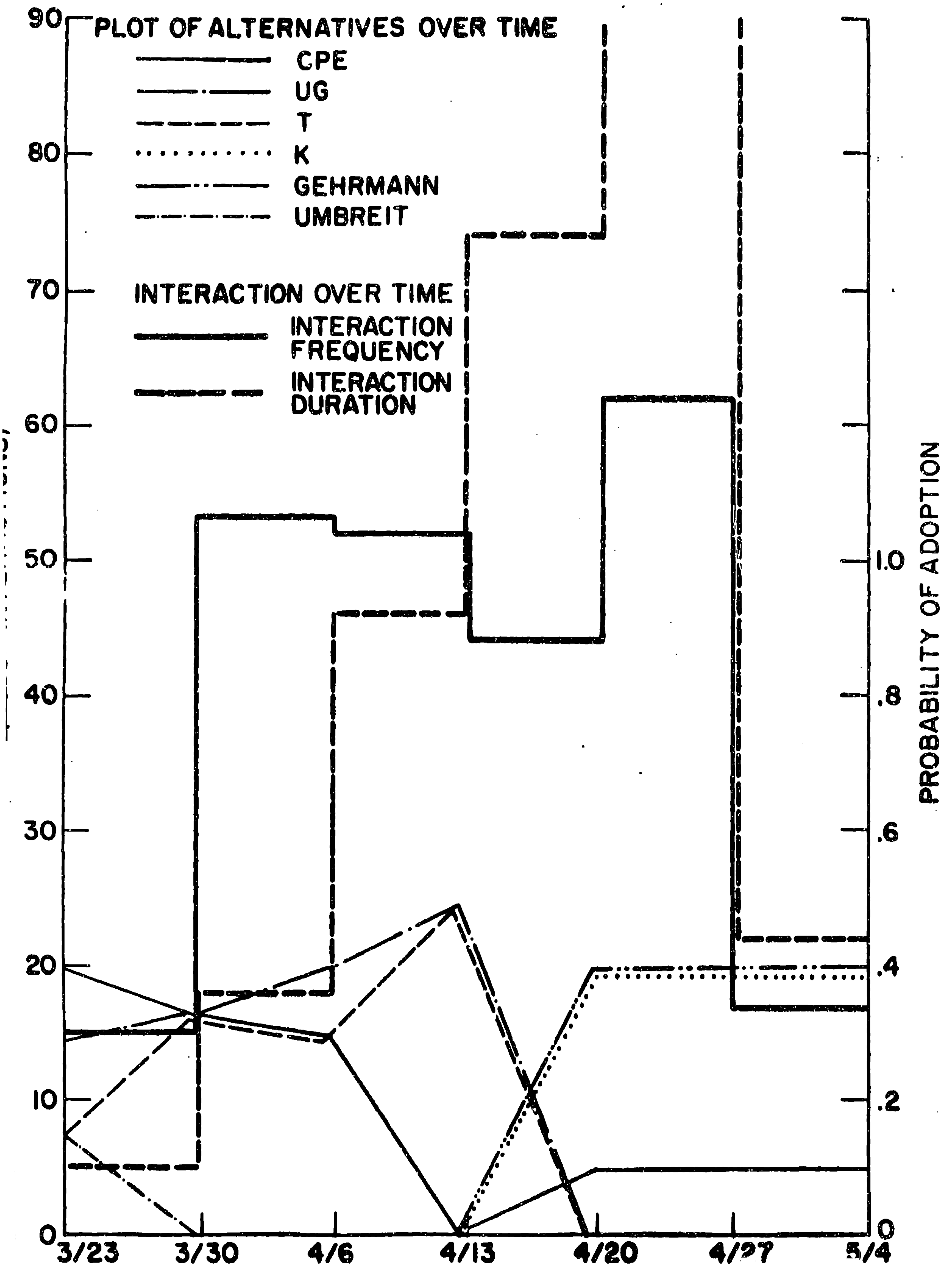
____________________________ ____________________________

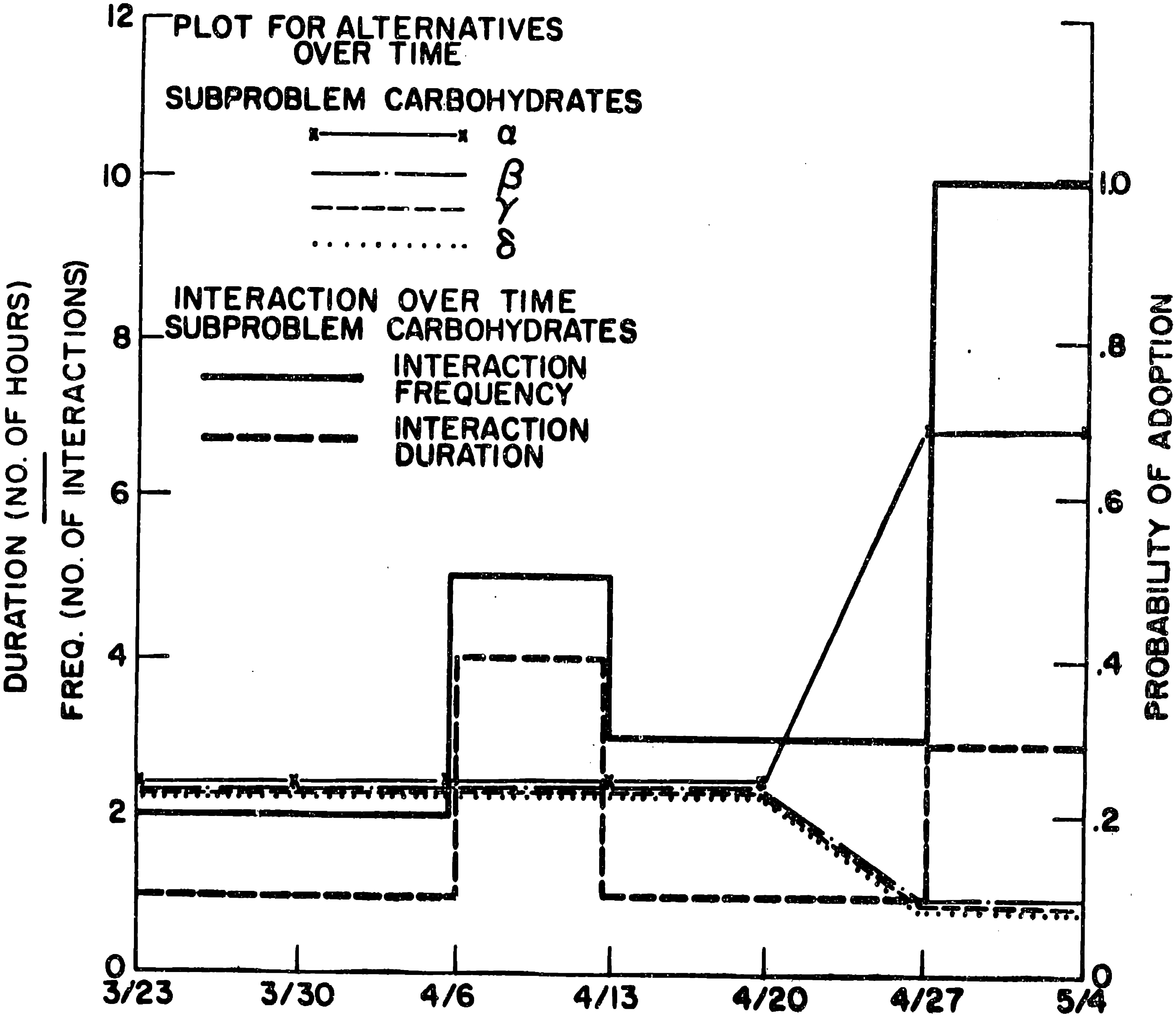
APPENDIX C

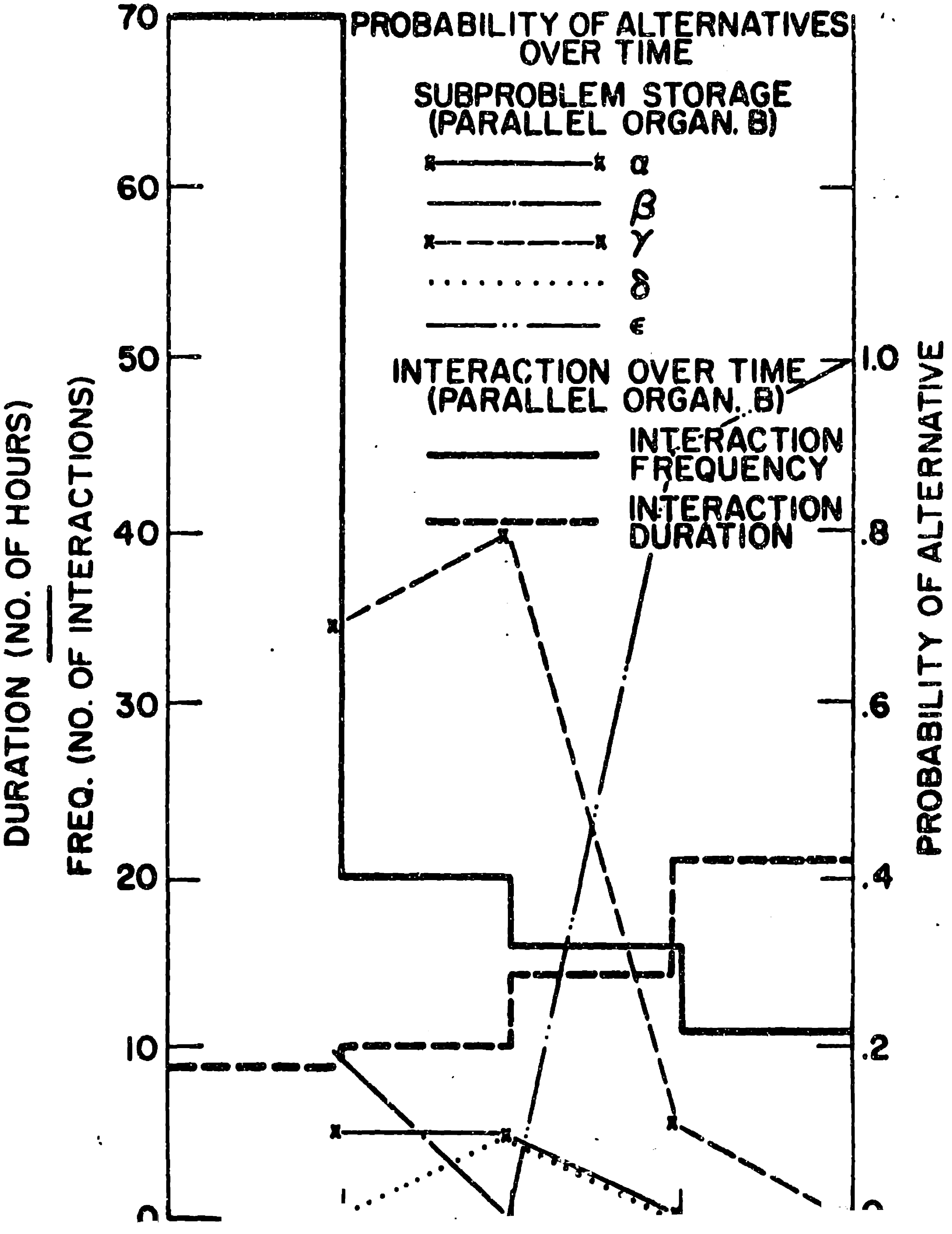
GRAPHS OF ALTERNATIVE PROBABILITIES RELATED TO INTERACTION


PLOT OF ALTERNATIVES OVER TIME (CARBOHYDRATES) METABOLISM
A
B
C
D
INTERACTION OVER TIME (CARBOHYDRATES)
INTERACTION FREQUENCY
INTERACTION DURATION
FREQ. (NO. OF INTERACTIONS)
PROBABILITY OF ADOPTION
0
1
2
3
4
5
6
7
.2
.4
.6
.8
1.0
3/23
3/30
4/6
4/13
4/20
4/27
5/4
TIME (WEEKS)


PROBABILITY OF ALTERNATIVES OVER TIME
SUBPROBLEM ϵ
A
B
C
D
INTERACTION OVER TIME
SUBPROBLEM ϵ
INTERACTION FREQUENCY
INTERACTION DURATION
FREQ. (NO. OF INTERACTIONS)
PROBABILITY OF ADOPTION
0
1
2
3
4
5
6
0
.2
.4
.6
.8
1.0
3/23
3/30
4/6
4/13
4/20
4/27
5/4
TIME (WEEKS)


PLOT OF ALTERNATIVES OVER TIME
CPE
UG
T
K
GEHRMANN
UMBREIT
INTERACTION OVER TIME
INTERACTION FREQUENCY
INTERACTION DURATION
PROBABILITY OF ADOPTION
90
80
70
60
50
40
30
20
10
0
1.0
.8
.6
.4
.2
0
3/23
3/30
4/6
4/13
4/20
4/27
5/4


PLOT FOR ALTERNATIVES OVER TIME
SUBPROBLEM CARBOHYDRATES
α
β
γ
δ
INTERACTION OVER TIME
SUBPROBLEM CARBOHYDRATES
INTERACTION FREQUENCY
INTERACTION DURATION
DURATION (NO. OF HOURS)
FREQ. (NO. OF INTERACTIONS)
PROBABILITY OF ADOPTION
0
2
4
6
8
10
12
.2
.4
.6
.8
1.0
3/23
3/30
4/6
4/13
4/20
4/27
5/4



PROBABILITY OF ALTERNATIVES OVER TIME
SUBPROBLEM STORAGE (PARALLEL ORGAN. B)
α
β
γ
δ
ϵ
INTERACTION OVER TIME (PARALLEL ORGAN. B)
INTERACTION FREQUENCY
INTERACTION DURATION
DURATION (NO. OF HOURS)
FREQ. (NO. OF INTERACTIONS)
PROBABILITY OF ALTERNATIVE
70
60
50
40
30
20
10
0
1.0
.8
.6
.4
.2
0

BIBLIOGRAPHY

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Cornell Society of Engineers
Registered Professional Engineer

Patents

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Publications

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